REMOTE ESTIMATION OF THE PROPERTIES OF SEA ICE SURFACE TRUTH MEASUREMENTS, BEAUFORT SEA, MARCH 1979

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Technical Report

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C-CORE

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The Centre for Cold Ocean Resources (C-CORE) was established at Memorial University of Newfoundland in St. John's in 1975. Its initial funding was provided by the Devonian Group of Charitable Foundations of Calgary. Ongoing funding now comes from government and industry.

The Centre's mandate is to undertake research that will assist the safe and orderly development of Canada's resources in cold and ice frequented oceans. C-CORE's main concentration of research is on ice, its properties, detection behaviour, on the interaction between oil and ice, and on seabed engineering.

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INTRODUCTION

As more work is carried out in the Canadian Arctic during winter, there exists a greater need for the ability to make remote estimates of the physical properties of sea ice (Mercer, 1980). The critical properties are the thickness and strength of ice, whether it be for operations on the ice surface, or movement of ice-breaking vessels. Although progress has been made in recent years in the observation and classification of sea ice using remote sensors (Campbell et al., 1975), little success has been achieved in remote measurement of ice thickness and strength. This ability is particularly important because of the high variability and dynamic nature of sea ice and the increased industrial activity in Canada's North.

In spite of this lack of success, there is promise of being able to sound sea ice using radio waves in or near the VHF band. At least three instruments are actively being developed in Canada which have possible application to the remote determination of sea ice thickness:

(1) Impulse radar systems, using braodband pulses in the 50 to 500 MHz frequency band (Rossiter et al., 1977; Rossiter, 1980; Butt and Gamberg, 1980).

(2) Synthetic pulse radar operating near 100 MHz (Tam and Keelty, 1980; Keelty and Tam, 1980).

(3) A pulsed 10 MHz system measuring the phases of three harmonies of the pulse repetition frequency of 1.28 MHz, (Hunt, 1980).

In addition, there have been measurements using lower frequency systems (Hoekstra et al., 1980), and there are developments in Great Britain (Oswald, 1980) and the U.S.S.R. (Bogorodsky 1980).

During 1978, a need was recognized for more effective co-ordination of research efforts in the field in Canada. As the result of a contract

arising from an unsolicited proposal to the Canadian Government (Department of Supply and Services), C-CORE mounted a joint government-industry-university program. Field measurements were made in the Beaufort Sea during March 1979 (Rossiter and Butt, 1979) and over Lake Melville, Labrador in April 1979 (Butt et al., 1979). The sites were chosen to coincide in time and place with other investigations, including the SURSAT Project, which involved a number of sea ice studies including a number of remote sensing overflights. This report describes the ice surface truth measurements made in the Beaufort Sea during this project. The other reports relating to this project are listed in Table 1.

Table 1 - Publication List

Remote Estimation of the Physical Properties of Sea Ice Project

C-CORE Reports:

Rossiter, J.R., and Butt, K.A., "Remote Estimation of the Properties of Sea Ice, Beaufort Sea Field Trip Report - March 1979, 36 pp., C-CORE Publications 79-9.

Butt. K.A., Gamberg, J.B., and Rossiter, J.R. "Remote Estimation of the Properties of Sea Ice, Impulse Radar Study of Lake Melville, Labrador" 248 pp., C-CORE Publication 79-9.

"Multi-year Ice Thickness Distribution in the Beaufort Sea Determined by Airborne Impulse Radar", 39 pp. plus appendices, C-CORE Publication 80-11.

Langhorne, P.J., Rossiter, J.R., and Keliher, T.E., "Remote Estimation of the Properities of Sea Ice, Ice Core Analysis, Beaufort Sea, March 1979", 171 pp., C-CORE Publication 80-7.

Rossiter, J.R., Gamberg, J.B., Gidney, G., Langhorne, P.J., Santos, R., and Snellen, J.B., "Remote Estimation of the Properties of Sea Ice, Analytical Techniques for Radar Sounding Data, Beaufort Sea, March 1979", C-CORE publication in preparation.

Rossiter, J.R., Butt, K.A., Ganberg, J.B., and Ridings, T., "Airborne Impulse Radar Sounding of Sea Ice", Proceedings of the 6th Canadian Symposium on Remote Sensing, Halifax, May 21-23, 1980, pp. C-CORE Publication 80-6.

The following papers appeared in the Proceeding of the International Workshop on the Remote Estimation of the Sea Ice Thickness, St. John's September 25-26, 1979, J.R. Rossiter and D.P. Bazeley eds., C-CORE Publication 80-5.

Rossiter, J.R., "Review of Impulse Radar Sounding of Sea Ice",pp.77-108.

Davis, J.L., "Electrical Property Measurements of Sea Ice in situ Using A Wideband Borehole and a Time-Domain Reflectometer", pp. 155-173.

Langhorne, P.J., "Crystal Anisotropy in Sea Ice", pp. 189-224.

Butt, K.A. and Gamberg, J.B., "Technology of Airborne Impulse Radar", pp. 385-412.

SURFACE MEASUREMENTS

Introduction

This report presents the ancillary surface truth measurements made during the field program of C-CORE's impulse radar sea ice study in the Beaufort Sea. The field program operated out of Polar Continental Shelf Project base camp at Tuktoyaktuk, N.W.T., and included experiments at eleven sites. A description of the sites and a summary of the data collected during the field program are presented in Table 2, the positions of the sites are shown in Figures 1 and 2.

Surface measurements were made at six of the sites listed in Table 2: Sites C1, C2, C4, C5, C6 and the multi-year ice site. The measurements made at each site include some or all of the following: augered ice thickness; salinity, from a number of sections of a core; density of a section of the core; temperature profiles, from thermistors embedded in a core or temperature probes installed in the ice. Site diagrams as well as brine volume profiles calculated from salinity and temperature profiles are included where possible.

Table 2. Site Locations and Data Collected Beaufort Sea, March 1979

C-1 Brackish ice; 69°25'30"N; 133°06'30"W, approximately 3 km south-west of Tuktoyaktuk.

- Impulse radar overflights, 300 MHz.
- Impulse radar surface traverse, 80, 300, and 400 MHz.
- NRC electrical properties - parallel rod capacitive measurements.
- NRC radar overflights - parallel and perpendicular polarizations.
- GSC time-domain reflectometry on two vertical planes at right angles.
- Augered holes for ice thickness.
- Cores for salinity, crystal and density analysis.
- SURSAT overflights and surface radiometry.
- Low level aerial photography.
- Threshold water current measurement.

C-2 Landfast, first-year sea ice; 69°51'N; 132°00'W; approximately 60 km north-east of Tuktoyaktuk.

- Impulse radar overflights, 300 MHz.
- Impulse radar surface test for anisotropic ice, 300 MHz.
- Augered holes for ice thickness.
- Cores for analysis.
- Ice temperature profile consisting of two separate profile measurements, one for the top 1 meter, the second for the bottom 1 meter with at least one point extending into the water column. Surface profile distance intervals were 10 cm; bottom profile increments approached 2 cm separation at the ice/water interface. Continuously recorded March 11 to March 25.
- SURSAT overflights.
- Low level aerial photography.
- Threshold water current measurements.

C-3 Fresh water pond; 69°30'N; 132°38'W; approximately 18 km north-east of Tuktoyaktuk.

Sometimes referred to by C-CORE party as "SURSAT pond".

- Impulse radar overflights, 80 and 300 MHz.
- SURSAT overflights and augered ice thickness holes.
- Low level aerial photography.

C-4 Landfast, first-year sea ice; 70°00'N; 132°00'W; approximately 70 km north-east of Tuktoyaktuk.

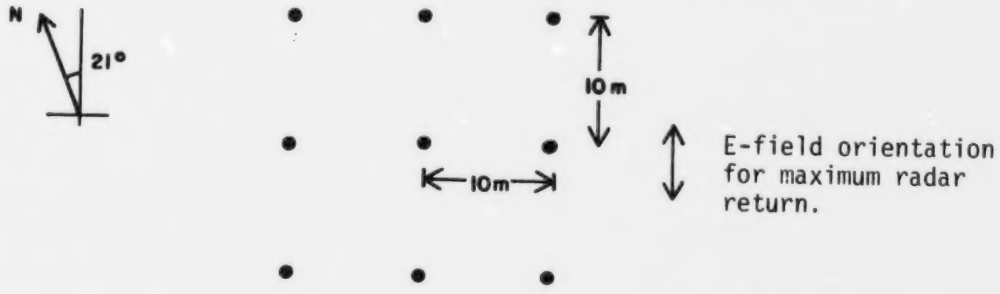
Also known as "Site A" by SURSAT team.

- Impulse radar overflights, 80 and 300 MHZ.
- Impulse radar surface traverses for anisotropic studies, 300 MHz and 400 MHz bistatic.

Table 2. Site Locations and Data Collected (cont'd)

- NRC electrical properties
- GSC borehole radar at one grid intersection, two planes.
- GSC time-domain reflectometry at each grid intersection, two planes.
- Impulse radar wide angle reflection and refraction on two planes at 90° with and without snow cover.
- Augered holes for ice thickness.
- Cores taken at each of nine grid intersections, plus some additional points.
- Temperature profiles at 10 cm intervals from the surface to the ice-sea water interface.
- SURSAT overflights, surface truth and scatterometer data.
- Low level aerial photography.
- Threshold water current measurements.

A square grid 20 m X 20 m was set up with cores taken 10 m apart (i.e. 9 cores).



The grid was aligned to the maximum impulse radar return.

C-5 First-year ice; southern edge of newly refrozen lead a few km north of C-4 along 132°W.

- Impulse radar overflight, 300 MHz.
- Cores taken for analysis.
- SURSAT overflights and scatterometer data.

C-6 First-year ice; northern edge of newly refrozen lead, approximately 8 km north of C-5.

- Impulse radar overflight, 300 MHz.
- Cores taken for analysis.
- SURSAT overflights.

"Multi-year" - Multi-year ice floes located in vicinity of ice island T-3. Same area as SURSAT multi-year site.

- Impulse radar overflight, 80 and 300 MHz.
- Impulse radar wide angle reflection and refraction in one plane over two ice types, 80 MHz.
- Impulse radar surface profiling, 80 and 300 MHz.

cont'd ...

Table 2. Site Locations and Data Collected (cont'd)

- Augered holes for ice thickness.
- Cores for salinity measurements.
- SURSAT overflights and surface truth data.
- Low level aerial photography.
- High level aerial photography (Esso).

Issungnak - Ice rubble field; 70°01'59.93"N; 134°18'50.62"W; approximately 72 km north-west of Tuktoyaktuk.

- Impulse radar overflights, 80 and 300 MHz.
- Low level aerial photography.
- SURSAT overflights.

Kugmallit Bay - main bay west of Tuktoyaktuk. Ice salinity appears to grade from brackish to typical first-year.

- Impulse radar overflights, 80 and 300 MHz.
- NRC radar overflights to Toker Pt.
- SURSAT overflights.

PCSP Pond - small frozen fresh water pond located immediately adjacent to the Polar Continental Shelf Project base camp on the opposite side of the main road.

- Impulse radar antenna tests.
- Augered thickness.
- NRC electrical properties.
- NRC radar overflights.
- SURSAT overflights, surface radiometry and scatterometer data

T-3 - Free drifting glacial ice island; 72° 37'N; 131°34'W (March 15, 1979 OMEGA position).

- Impulse radar overflights, 300 MHz.
- SURSAT overflights
- High level photography

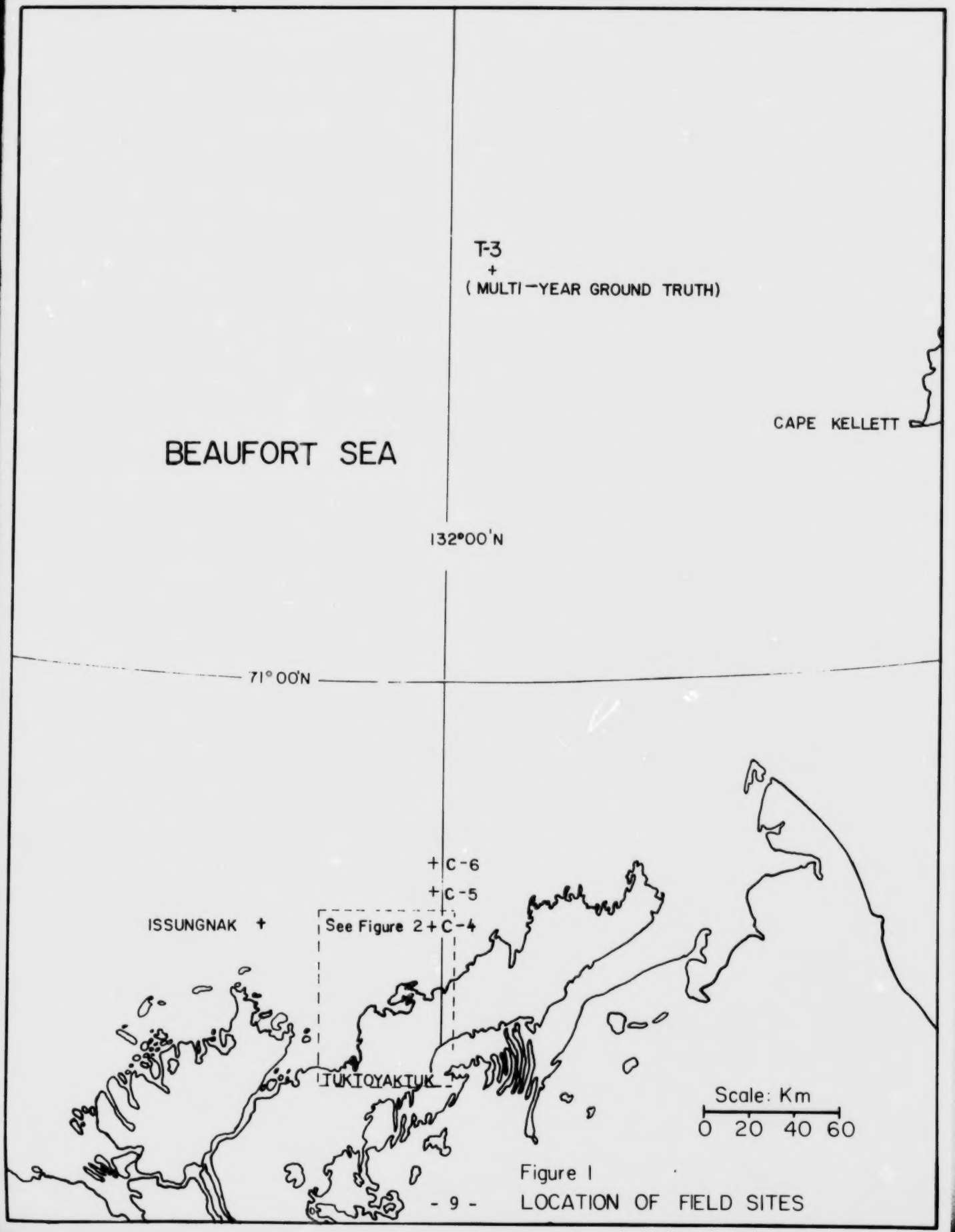


Figure 1
LOCATION OF FIELD SITES

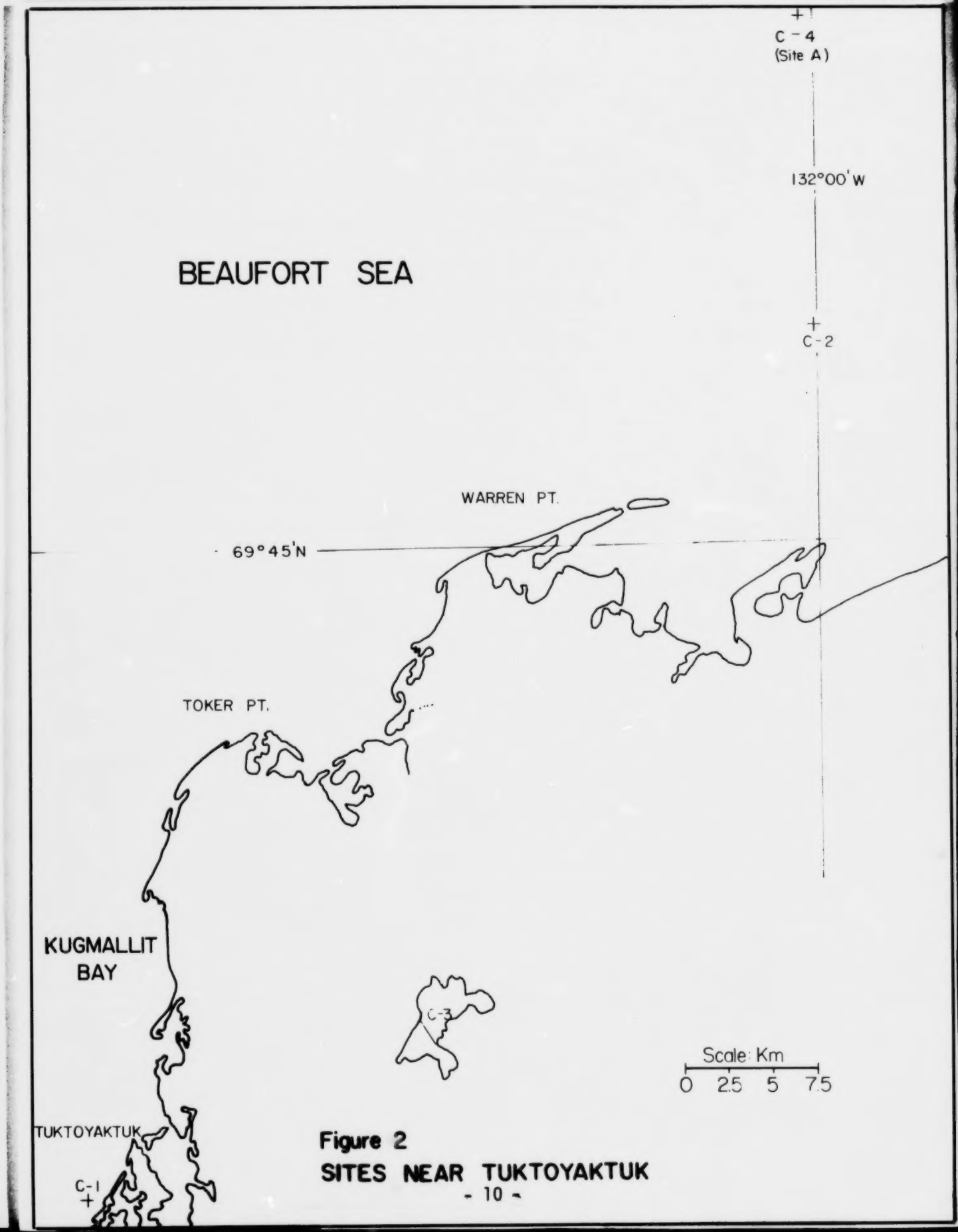


Figure 2
SITES NEAR TUKTOYAKTUK

Ice Coring

A 3-inch diameter SIPRE corer with extensions was used to take ice cores. The ice cores, once removed from the corer, were cut typically every 10 cm from the ice surface down. A 2 cm thick slice for salinity analysis and a 1 cm thick slice for horizontal section crystal analysis (Langhorne, et al, 1980) were taken at each division. The section from 23 to 30 cm down from the ice surface was used typically for the density measurement. The specific sectioning of each core is documented in the core summary table (Table 3). The sections were returned to base camp in a frozen condition, where the salinity samples were allowed to melt before analysis. Some of the 1 cm sections for crystal analysis were returned to St. John's in core cylinders packed in dry ice.

Ice Temperature Profiles

Obtained from Cores: A set of thermistors and a Digital Multi-Meter (D.M.M.) were used to determine the temperature profiles of two cores at Site C4 and one at the multi-year site; immediately after they were removed from the corer. A handheld drill was used to drill small holes from the side into the middle of the core, a thermistor was inserted in each hole then the resistance of the thermistor (measured with the D.M.M.) and the distance from the ice surface were recorded. The thermistor resistance values were converted to temperature readings using the thermistor calibration (Table 4). The temperatures obtained were plotted against the distance from the ice surface to obtain a temperature profile (Figure 3; Tables 5, 6 and 7).

Recording Thermistor Probe: A probe to monitor the temperature profile through the ice directly was installed at Site C2. The probe, installed on March 17, 1979, consisted of two urethane-filled tubes with thermistors

CORE NO.	LOCATION	DATE (MAR.)	PERSONNEL	ORIENTATION	LENGTH (cm)	ICE THICKNESS (cm)	FREE-BOARD (cm)	SALINITY	DENSITY	THIN SECTION PHOTOGRAPHS	C AXIS MEASUREMENTS	BROUGHT BACK FROM FIELD	COMMENTS
C1-1	Close to NORDA experiment at C1	9th	C-CORE & NORDA		113	130		NORDA have top 60 cm of profile C-CORE cut remaining in 5 cm sections					Core temperatures taken by NORDA
C1-2	Site C1	N/A	C-CORE (Treve Bonser)		146			In 2 cm thick sections every 10 cm	Section from 23-30 cm from ice surface				
C2-1	Close to current meter at C2	11th	C-CORE	197°T	115?	139		"	Section from 55-60 cm from ice surface				
C2-4	Close to current meter at C2	13th	C-CORE	180°T	145?			"	Section from 23-30 cm from ice surface			Section at 10 cm intervals from 20 to 90 cm depth and 5 cm intervals from 110 to 145 cm depth	
C4-1	To E of grid at C4	12th	C-CORE & SURSAT	0°T	105	106	8	"	"				Skeletal layer thickness = 3cm

Table 3 - Summary of Cores Taken

Text Resumes On Pg. 22

CORE NO.	LOCATION	DATE (MAR.)	PERSONNEL	ORIENTATION	LENGTH (cm)	ICE THICKNESS (cm)	FREE BOARD (cm)	SALINITY	DENSITY	THIN SECTION PHOTOGRAPHS	C AXIS MEASUREMENTS	BROUGHT BACK FROM FIELD	COMMENTS
C4-2	About 100 yds. N of C4-1	14th	C-CORE	142°T	103	107		In 2 cm thick sections every 10 cm	Section from 23-30 cm from ice surface				
C4-3	(-½, -½) current meter hole	19th	C-CORE	antenna E field for minimum return, 111°T	112	115		"	"	Every 10 cm from 2 cm to 102 cm depth	At levels 32/33 62/63 92/93 102/103		Photograph of core taken in field
C4-4	(0,0) non recording thermistor probe	19th	C-CORE	111°T	112	112		"	"	Every 10 cm 2 cm to 72 cm depth, every 5 cm from 72 to 102 cm depths	At levels 32/33 62/63 102/103		Photograph of core taken in field
C4-5	(1, -1)	19th	C-CORE	111°T	111	113		"	"	Section 102/103	Section 102/103	Sections at 10 cm intervals from 2 to 92 cm	"
C4-6	(1, 0)	20th	C-CORE	111°T	112	115		"	"	"	"	"	Photograph of core taken in field. core temps. measured from 5-50 cm depth
C4-7	(1, 1)	20th	C-CORE	111°T	98	115	9 (after refrozen)	"	"	Section 92/93	Section 92/93	Sections at 10 cm intervals from 2 to 82 cm	Bottom portion of core lost when core was taken

Table 3 (Cont'd)

CORE NO.	LOCATION	DATE (MAR.)	PERSONNEL	ORIENTATION	LENGTH (cm)	ICE THICKNESS (cm)	FREE BOARD (cm)	SALINITY	DENSITY	THIN SECTION PHOTOGRAPHS	C AXIS MEASUREMENTS	BROUGHT BACK FROM FIELD	COMMENTS
C4-8	(0, 1)	20th	C-CORE	111°T	112½	115	7 (after refrozen)	In 2 cm thick sections every 10 cm	Section from 23-30 cm from ice surface	Section 102/103	Section 102/103		Photograph of core taken in field
C4-9	(0, -1)	21st	C-CORE	111°T	114	117	13	"	"	"			Photograph of core taken in field, core temperatures measured from 30-110 cm depth
C4-10	(-1, -1)	21st	C-CORE	111°T	114	117	13	"	"	Section 102/103	Section 102/103	Sections at 10 cm intervals from 2-92 cm	
C4-11	(-1, 0)	21st	C-CORE	111°T	113	115	12½	"	"	"	"	"	
C4-12	(-1, 1)	21st	C-CORE	111°T	113½	116	11	"	"	"	"	"	Photograph of core taken in field
C4-13	(0, -½)	21st	C-CORE	111°T	114							Full core	
C4-14	(0, -1)	25st	C-CORE	111°T	118	120				At levels 32/33 62/63 102/103	At levels 32/33 62/63 102/103	Sections 2/3 to 22/23 42/43 to 52/53 72/73 to 92/93	Core also referenced to 0°T

Table 3 (Cont'd)

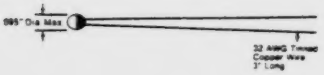
CORE NO.	LOCATION	DATE (MAR.)	PERSONNEL	ORIENTATION	LENGTH (cm)	ICE THICKNESS (cm)	FREE BOARD (cm)	SALINITY	DENISTY	THIN SECTION PHOTOGRAPHS	C AXIS MEASUREMENTS	BROUGHT BACK FROM FIELD	COMMENTS
C4-15	(0, 1)	25th	C-CORE	111°T	120				Section from 23-30 cm from ice surface	At levels 32/33 62/63 102/103	At levels 23/33 62/63 102/103	Sections 2/3 to 22/23 42/43 to 52/53 72/73 to 92/93	Core also referenced to 0°T
C5-1	From newly refrozen lead on south shore of large lead to the N of C4	12th	C-CORE & SURSAT	0°T	34	30		In 2 cm thick sections every 10 cm	"			Sections 10/11 21/22 30/31	
C5-2	As C5-1	12th	C-CORE & SURSAT	0°T	31	30		"					
C6-1	Refrozen lead close to C6-2	12th	C-CORE & SURSAT	0°T	25	25		"				Sections 2/3 12/13 32/33	
C6-2	Thicker first year ice at C6	12th	C-CORE & SURSAT	0°T	125	125		"	Section from 23-30 cm from ice surface			Sections at 10 cm intervals from 32 to 112 cm + Section 120/121	
CM-1	Melt pond on multi-year	15th	Esso (G. Spedding)		88			"	Sections from 23-30 and 13-20 cm from ice surface			Sections at 10 cm intervals from 2 to 82 cm	

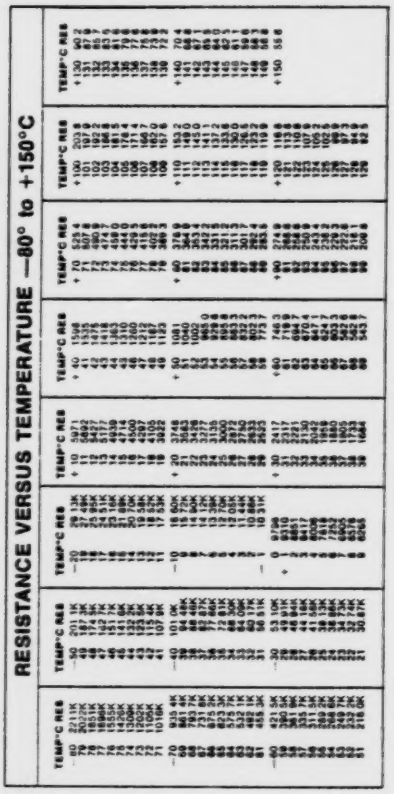
Table 3 (Cont'd)

CORE NO.	LOCATION	DATE (MAR.)	PERSONNEL	ORIENTATION	LENGTH (cm)	ICE THICKNESS (cm)	FREE BOARD- (cm)	SALINITY	DENSITY	THIN SECTION PHOTOGRAPHS	C AXIS MEASUREMENTS	BROUGHT BACK FROM FIELD	COMMENTS
CM-2	Ridge on	15th	Esso (G. Spedding)		88			In 2 cm thick sections every 10 cm	Section from 23-30 cm from ice surface			Sections at 10 cm intervals from 2 to 82 cm	
IM	Large hummock at 72°37'N 131°34'W See diagram in salinity book	14th	SURSAT		166	>1200		Sections at 26, 64, 111 and 148 cm		Horizontal & Vertical ?			Sail height = 3 metres
IIM	Small hummock at 72°37'N 131°34'W See diagram	14th	SURSAT		161	800		7 salinities, no depths		Horizontal & Vertical ?			Sail height = 1 metre
IIIM	Small deep melt pond at 72°37'N 131°34'W See diagram	14th	SURSAT		173	550	23			Horizontal & Vertical ?			
IVM	Shallow melt pond at 72°37'N 131°34'W See diagram	14th	SURSAT		89	550		In 5 cm thick sections every 10 cm		Horizontal & Vertical		Sections A (top of core) to I, alternate 5 cm sections	Sail height = 0.5 metres

Table 3 (Cont'd)

YSI PRECISION THERMISTOR





YSI PRECISION THERMISTOR

YSI 44005

RESISTANCE 3000 OHMS @25°C

Interchangeability: ±0.2°C (See Tolerance Curves).

Max. Operating Temp: 150°C (300°F).

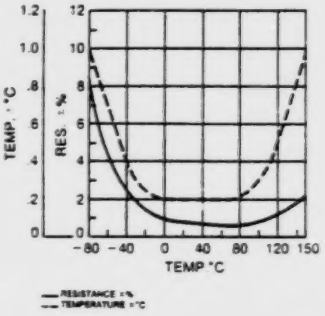
Time Constant, Max: 1 sec. in well stirred oil, 10 sec. in still air. Time constant is the time required for a thermistor to indicate 63% of a newly impressed temperature.

Dissipation Constant, Min: 8mW/°C in well stirred oil, 1mW/°C in still air. Dissipation constant is the power in milliwatts to raise a thermistor 1°C above surrounding temperature.

Color Code: Black epoxy body, green end.

Storage Temperature: -80° to +120°C (-112° to +250°F).

Tolerance Curves: The following curves indicate conformance to standard resistance temperature values as a % of resistance, and as a maximum interchangeability error expressed as temperature.



WARNING

Use heat sinks when soldering or welding to thermistor leads.

Table 4 Thermistor Calibration

Partial Ice Temperature Profiles. (see Tables 5, 6, 7)

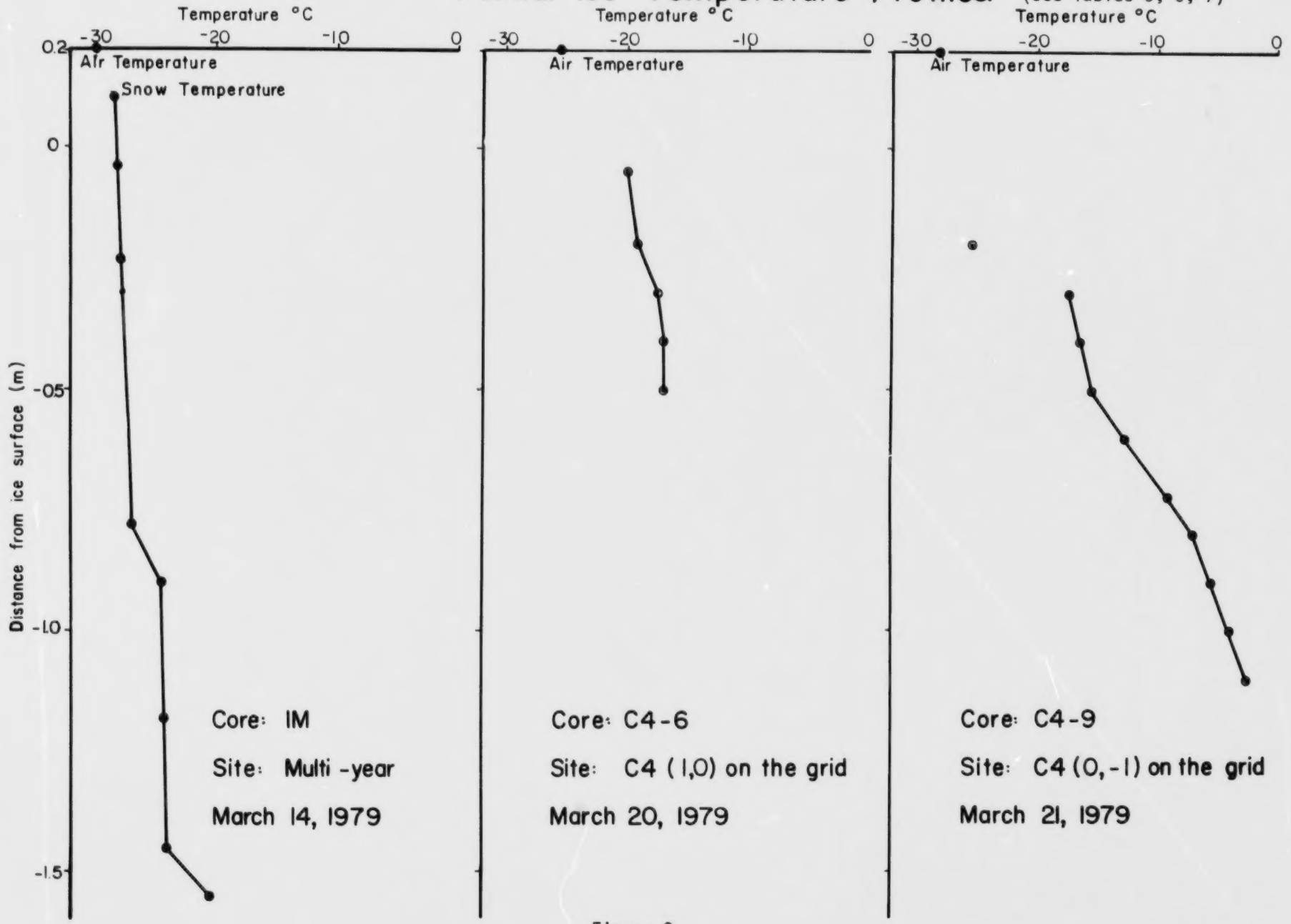


Figure 3

TABLE 5

PARTIAL ICE TEMPERATURE PROFILE

CORE IM

March 14, 1979

MULTI-YEAR SITE

DISTANCE from ice surface (m)		TEMPERATURE (^{o}C)
+0.20	Air	-30.0
+0.10	Snow	-28.5
-0.04		-28.5
-0.23		-28.0
-0.30		-27.8
-0.78		-26.0
-0.90		-24.5
-1.18		-24.2
-1.45		-24.0
-1.55		-20.5

TABLE 6

PARTIAL ICE TEMPERATURE PROFILE
from THERMISTORS EMBEDDED IN CORE
Core C4-6
March 20, 1979
Site C4, (1,0) on the Grid

DISTANCE FROM ICE SURFACE (m)	THERMISTOR RESISTANCE (kΩ)	TEMPERATURE (^{o}C)
-0.05	28.9	-19.9
-0.20	27.9	-19.2
-0.30	25.4	-17.6
-0.40	24.5	-17.0
-0.50	24.5	-17.0

TABLE 7

PARTIAL ICE TEMPERATURE PROFILE

from THERMISTORS EMBEDDED IN CORE

CORE C4-9

March 21, 1979

Site C4, (0,-1) on the Grid

DISTANCE FROM ICE SURFACE (m)	THERMISTOR RESISTANCE (kΩ)	TEMPERATURE (^{o}C)
+0.20	47.8	-28.3
-0.10	Break in core	
-0.20	40.3 (inaccurate)	-25.6
-0.30	25.1	-17.5
-0.40	24.0	-16.6
-0.50	22.7	-15.6
-0.60	19.4	-12.8
-0.72	15.8 (close to a break)	- 9.1
-0.80	14.2	- 7.1
-0.90	13.1	- 5.6
-1.00	11.9	- 4.0
-1.10	11.2	- 2.6

mounted in holes in the tubes. Readings from each of the thermistors were multiplexed on to a Rustrak chart recorder. Further information about the recording thermistor probe, the processing of the temperature charts and the temperature data collected using the recording themistor probe is in the section "SITE C2".

Non-Recording Thermistor Probe: On March 19, 1979, a non-recording thermistor probe consisting of a single urethane-filled tube with thermistors, was installed at Site C4, co-ordinates (0,0) on the site grid. The resistance of the thermistors was read with a D.M.M. and recorded for each thermistor. The temperature data collected using the non-recording thermistor probe, and specifications of the thermistor spacing, are in the section "SITE C4".

Salinity

Samples of brine from the sections of the ice core that were allowed to melt for salinity analysis, were placed in the conductivity cell of an Electronic Instruments Ltd. Model MC-1 Mk V conductivity meter. The conductivity and the sample temperature were measured and recorded. The conversion from sample temperature and conductivity to salinity was done on a Hewlett Packard 97 programmable calculator using a conversion program to interpolate the conductivity meter calibration done at Scott Polar Research Institute to $\pm$ 0.5% or closer.

Some of the samples were returned to St. John's for a verification of the salinity by titration at the Water Analysis Facility, MUN. The salinity values obtained by titration (referred to here as "Analytical Salinities") were significantly lower than the salinity values obtained from the conductivity and sample temperature measurements (referred to as "Calculated Salinities") in approximately 50% of the cases. The differences were in the order of 1 or 2 parts per thousand, ($^{o}/_{oo}$), in salinities of less than $10^{o}/_{oo}$, obviously in

excess of the <1% error specified for the conductivity meter and salinity calculation.

No satisfying explanation for this discrepancy was found. However, the accuracy of the titration decreases if the samples are too small or if the salinity is too low. Another possible explanation lies in the process of shipping small sample vials. Extremely cold conditions in the first stage of travel from Tuktoyaktuk to St. John's may have caused some of the samples to freeze. The resulting expansion may have broken the seal on the sample bottles, allowing some liquid to evaporate or salts to diffuse out. (Robertson, D.E., 1972).

The general trend for higher salinity and more consistent behaviour with depth indicate that the calculated salinities are more likely to be correct.

Brine Volume

Calculations to convert from temperature and salinity to brine volume were done on a Hewlett Packard 97 programmable calculator using equations published by Frankenstein and Gardner (1967). For θ = temperature in ^{o}C, S = salinity in parts per thousand and ν = brine volume in parts per thousand:

$$\nu = S\left(\frac{43.795}{101} + 1.189\right) \qquad \text{for } -22.9^{o} \leq \theta \leq -8.2^{o} \qquad (1)$$

$$\nu = S\left(\frac{45.917}{101} + 0.930\right) \qquad \text{for } -8.2^{o} \leq \theta \leq -2.06^{o} \qquad (2)$$

$$\nu = S\left(\frac{52.56}{101} - -2.28\right) \qquad \text{for } -2.06^{o} \leq \theta \leq -0.5^{o} \qquad (3)$$

For values of temperature lying outside the range $-22.9^{o}C$ to $-0.5^{o}C$ brine volumes were obtained from a table by Assur (1958).

Density

Ice core densities were measured at the Tuktoyaktuk base camp, using Archimedes' principle. The apparatus consisted of a triple-beam

balance, a lab beaker, some thin string and JP4 kerosene jet fuel.

Using the balance, the mass of the beaker with liquid (m_b), the mass of the beaker with the ice sample suspended in the liquid (m_s) and the mass of the beaker and liquid with the sample resting on the bottom of the beaker (m_i) were determined. The mass of the ice sample is ($m_i - m_b$), the mass of the kerosene displaced by the ice sample is ($m_s - m_b$) and the density of the ice sample is obtained by multiplying $\left(\frac{m_i - m_b}{m_s - m_b}\right)$ by the density of the jet fuel at the testing temperature. The density (ρ) of JP4 was specified by the supplier as 0.751 g/cm^3 at 15.6°C. Since the density of JP4 as a function of temperature was not readily available, the specified density was used, and the temperature during the density measurements was kept between -20 to -13°C. Errors caused by uncertainty in the absolute density of JP4 are likely to be small.

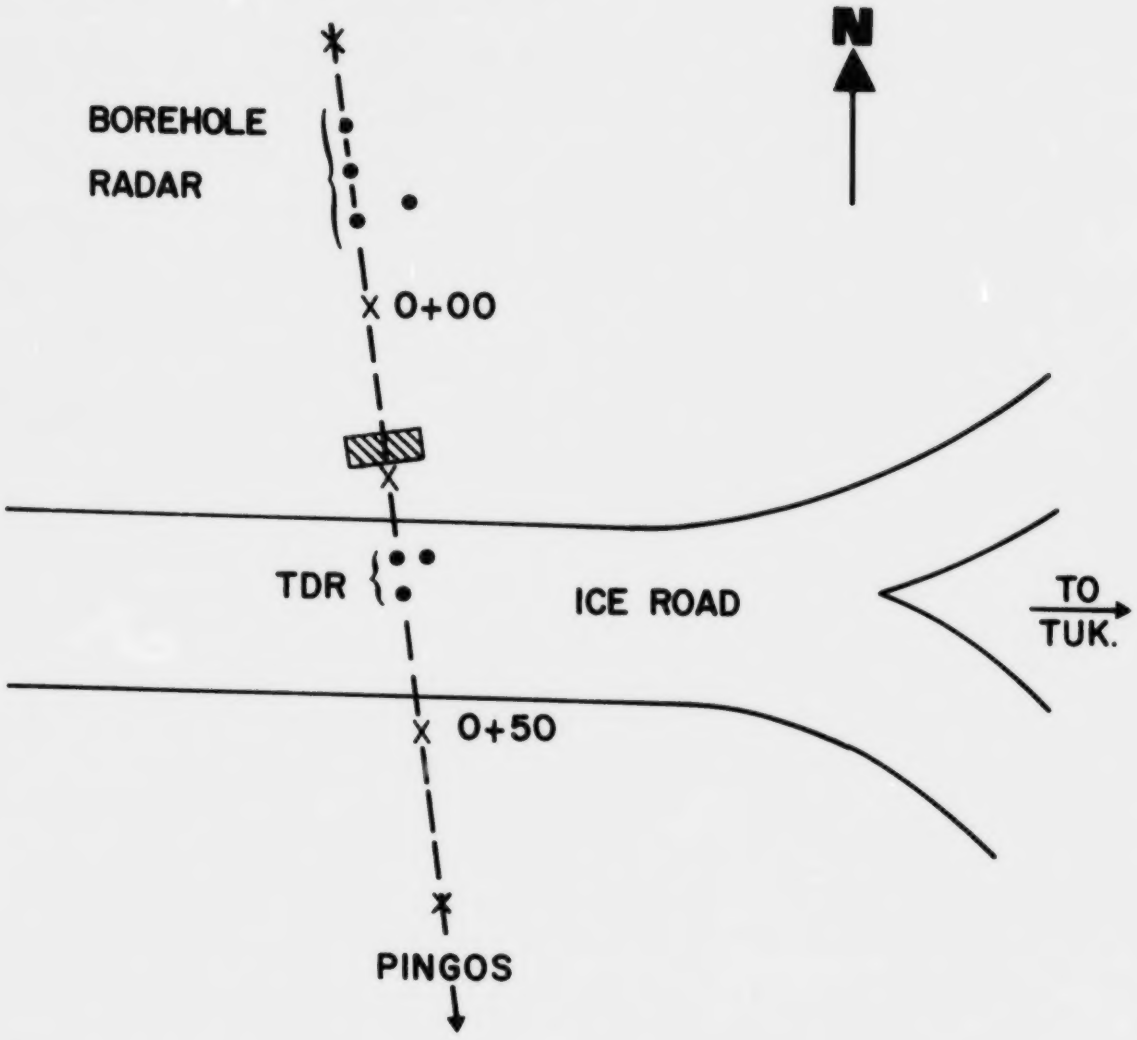
Core Tables

For each core taken the following measurements have been tabulated: (1) the measured melt-sample conductivity; (2) temperature; (3) calculated salinity; (4) salinity from titration; (5) measured ice temperature; (6) calculated brine volume; and, (7) density. The sample codes indicate the core number and the distance from the ice surface in cm; for example, C4-3 20/22 indicates the third core at site C4, the section from 20 to 22 cm beneath the ice surface. A summary of the cores is given in Table 3. Further details are documented in the individual core tables.

SITE C1

Site C1 was established as a typical brackish ice site in the outflow of the Mackenzie River. The site coincided with NORDA site 3, and was located by driving along the seasonal ice road and lining up on the two Tuk pingos. See Figure 4 for site layout. Table 8 gives the information gathered from a core at the site.

Site C–I



Legend:

X Flag

Reflector

Figure 4

Table 8

CORE C1-2

DATE 23 March 1979

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity PPT	Ice Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
C1-2 0/2	5950	16	3.98		-18	14.4		
C1-2 10/12	1467	15	0.95		-17	3.6		
C1-2 20/22	179	13	0.12		-16	0.5		
C1-2 23/30								0.875
C1-2 30/32	15.27	12.5	0.01		-15	0.0		
C1-2 40/42	15.25	12	0.01		-13.5	0.0		
C1-2 50/52	21.9	11.5	0.02		-12.5	0.1		
C1-2 60/62	8.11	11	0.0		-11	0.0		
C1-2 70/72	15.72	13.5	0.01		-9.5	0.1		
C1-2 80/82					-8.5			
C1-2 90/92	9.61	13	0.01		-6.5	0.1		
C1-2 100/102	7.86	12	0.01		-6	0.1		
C1-2 110/112	13.95	12	0.01		-4	0.1		
C1-2 120/122	22.3	11.5	0.02		-3	0.3		
C1-2 130/132	43.8	12	0.03		-2	0.7		
C1-2 140/142	28.2	12	0.02		-1	1.0		

COMMENTS:

1 From Calculated Salinity
2 From Analytical Salinity

SITE C2

Site C2 was established, after aerial reconnaissance, as a typical landfast first-year ice site. C2 was chosen as the location for the recording thermistor probe, and on March 11, 1979 the probe was installed. The information from the cores taken at the site is in Tables 9 and 10. Brine volumes have not been calculated for the two cores, because a good temperature profile, close in time, was not available. Temperature profiles from the recording thermistor probe become applicable later in time, and could be used assuming that the salinity profile remains constant over that period.

Table 9

CORE C2-1

DATE 11 March 1979

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity PPT	Ice Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
C2-1 2/4	5950	16	4.0					
C2-1 11/13	7200	13	5.3					
C2-1 22/24	6570	14	4.7					
C2-1 32/34	N.S.	N.S.	N.S.					
C2-1 41/43	5450	14	3.8					
C2-1 51/53	4390	13	3.1					
C2-1 55/60								0.876
C2-1 61/63	3780	13	2.7					
C2-1 71/73	4070	14	2.8					
C2-1 82/83	3150	14	2.1					
C2-1 91/93	2420	14	1.6					
C2-1 101/103	1820	14	1.2					
C2-1 111/113	2020	16	1.3					
C2 Water	10450	20	6.6					

COMMENTS:

Table 10

CORE C2-4

DATE 13 March 1979

Sample Cod	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity PPT	Ice Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
C2-4 2/4	7900	12	6.0					
C2-4 11/13	7750	12	5.8					
C2-4 21/23	5950	12	4.4					
C2-4 23/30								0.882
C2-4 31/33	6500	13	4.7					
C2-4 41/43	5950	11	4.5					
C2-4 51/53	4170	10	3.2					
C2-4 61/63	1670	10	1.2					
C2-4 71/73	3510	11	2.6					
C2-4 81/83	3800	11	2.8					
C2-4 91/93	N.S.	N.S.	N.S.					
C2-4 101/113	2360	11	1.7					
C2-4 111/113	2030	12	1.4					
C2-4 121/123	1920	12	1.4					
C2-4 131/133	1090	12	0.76					
C2-4 141/143	1222	13	0.83					

COMMENTS:

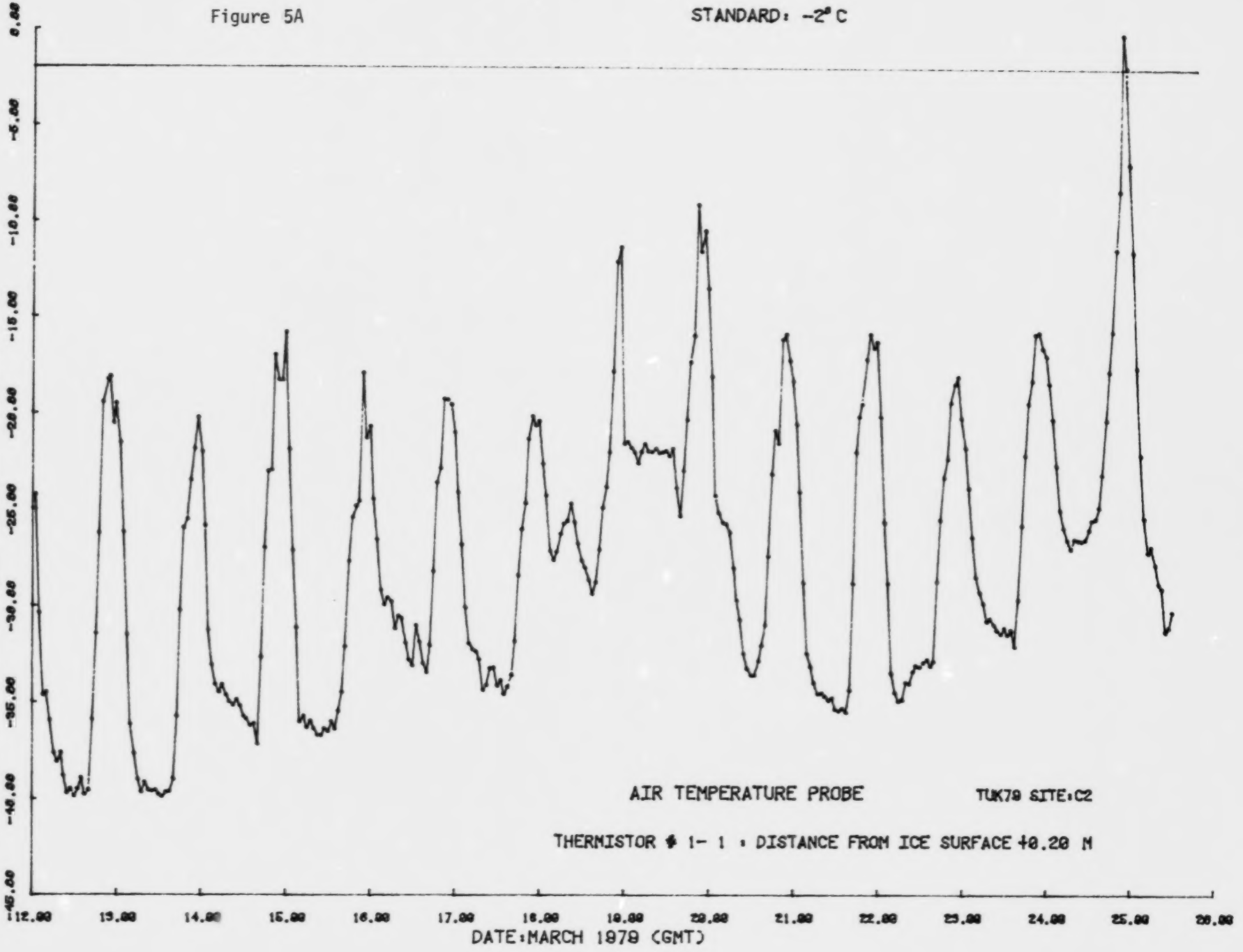
Site C2 Recording Thermistor Probe

Installation Date:	March 11, 1979 at 2310 H	G.M.T.
Ice Data:	Ice Thickness	1.29 m
	Snow Cover	0.13 m
	Freeboard	0.09 m
	Air Temperature	-33° C
	(at 0000 H G.M.T.	March 12, 1979)

The spacing of thermistors in the urethane-filled tubes was arranged so that there would be a uniform sampling of the temperature throughout the ice sheet and a concentrated sampling near the ice surface and bottom (Figure 7.) Two tubes allowed for a large range of possible ice thicknesses, one tube having a concentration of thermistors near the ice surface where the largest temperature gradients exist, and the second tube having concentration of thermistors for detailed study of temperature near the ice-water interface. The temperature ranges for the two probes were chosen to cover the expected extrema adequately. The upper probe has the range -50° to +5° C and the lower probe has the range -10^{o} to 0^{o}C. These ranges were sufficient, except for thermistor 2-2 at -0.48 m from the ice surface, where the temperature was below -10^{o} C.

The raw data from the recording thermistor probe consists of 14 days of quarter-hourly ice temperature profiles encoded on a Rustrak Chart Roll. A more manageable form for the data was adopted and the temperature behaviour of each individual thermistor in the probe was plotted against time (a decimal day rather than a day divided into 24 hours was adopted for convenience). The resulting 24 graphs are given in Figures 5 A to 5 X. They show that the seawater under the ice remained nearly constant at -0.9° C, that the air temperature varied cyclically with

Figure 5A



Text Resumes On Pg. 59

Figure 5B

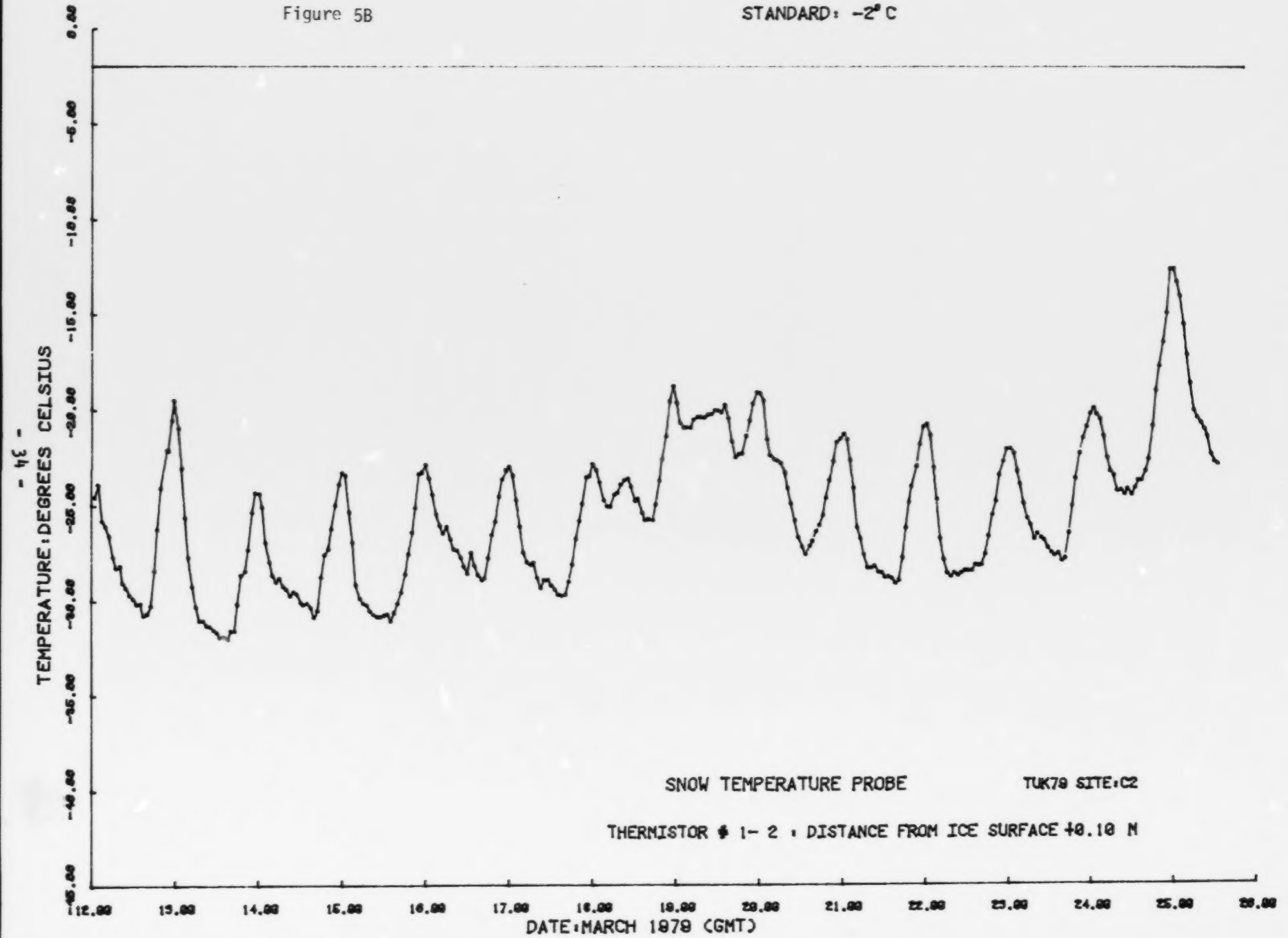

STANDARD: -2° C
TEMPERATURE:DEGREES CELSIUS
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
-45.00
SNOW TEMPERATURE PROBE
TUK79 SITE:C2
THERMISTOR # 1- 2 : DISTANCE FROM ICE SURFACE +0.10 M
12.00
13.00
14.00
15.00
16.00
17.00
18.00
19.00
20.00
21.00
22.00
23.00
24.00
25.00
26.00
DATE:MARCH 1979 (GMT)

Figure 5C

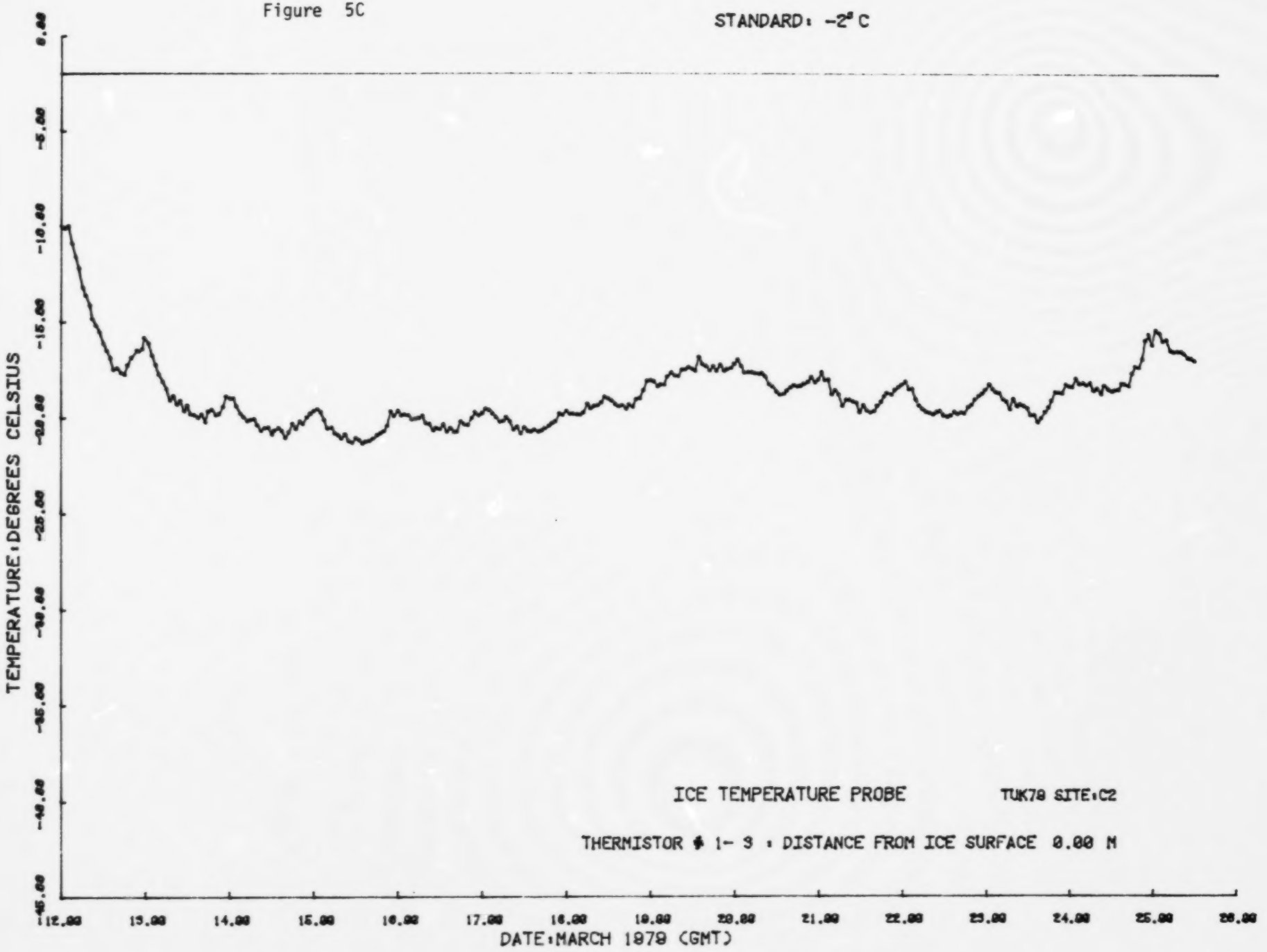

STANDARD: -2° C
TEMPERATURE:DEGREES CELSIUS
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
-45.00
ICE TEMPERATURE PROBE
TUK79 SITE:C2
THERMISTOR # 1- 3 : DISTANCE FROM ICE SURFACE 0.00 M
12.00
13.00
14.00
15.00
16.00
17.00
18.00
19.00
20.00
21.00
22.00
23.00
24.00
25.00
26.00
DATE:MARCH 1979 (GMT)

Figure 5D

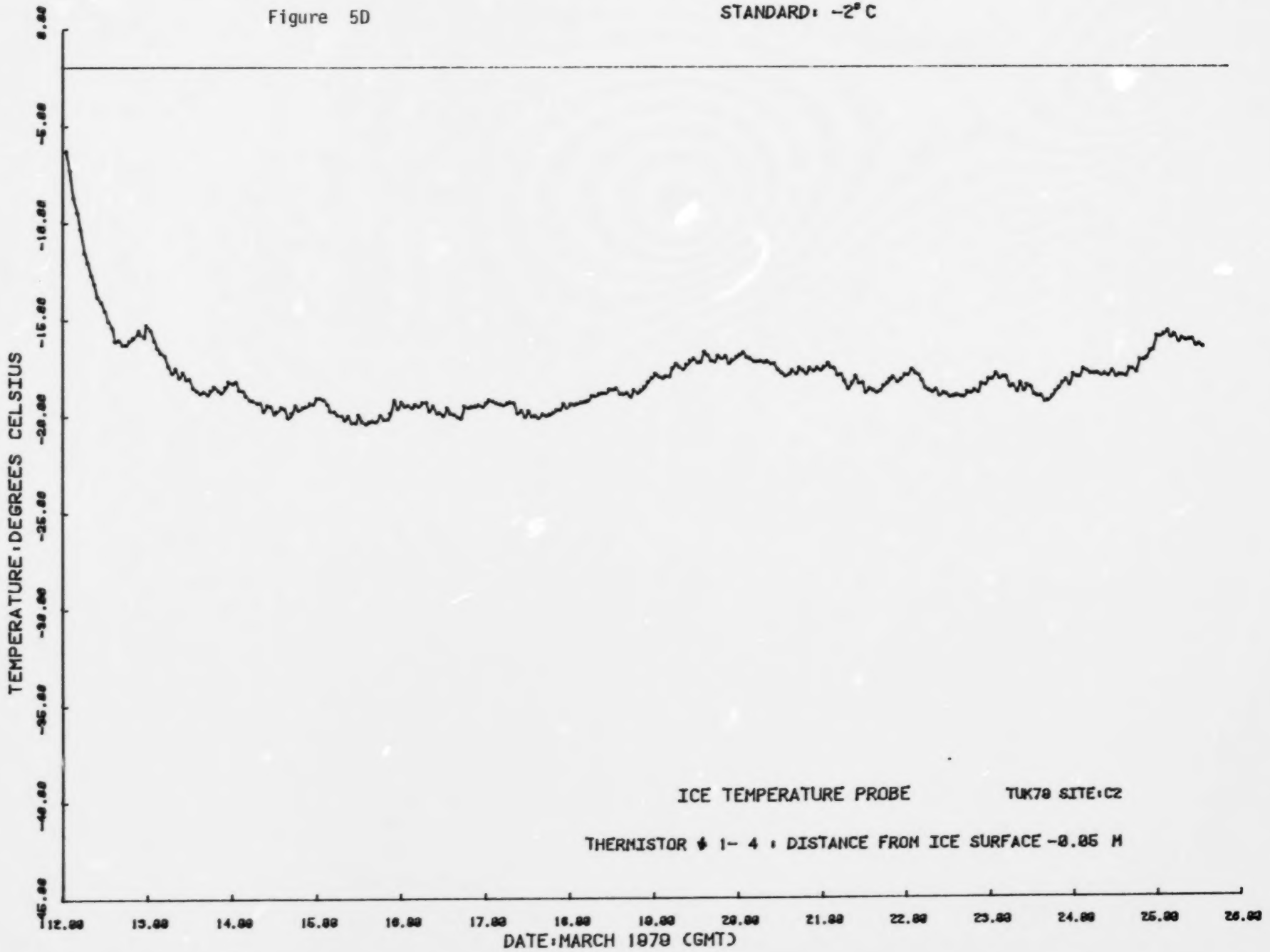

STANDARD: -2° C
TEMPERATURE:DEGREES CELSIUS
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
-45.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
19.00
20.00
21.00
22.00
23.00
24.00
25.00
26.00
DATE:MARCH 1979 (GMT)
ICE TEMPERATURE PROBE
TUK79 SITE:C2
THERMISTOR # 1- 4 : DISTANCE FROM ICE SURFACE -0.05 M

Figure 5E

STANDARD: -2° C

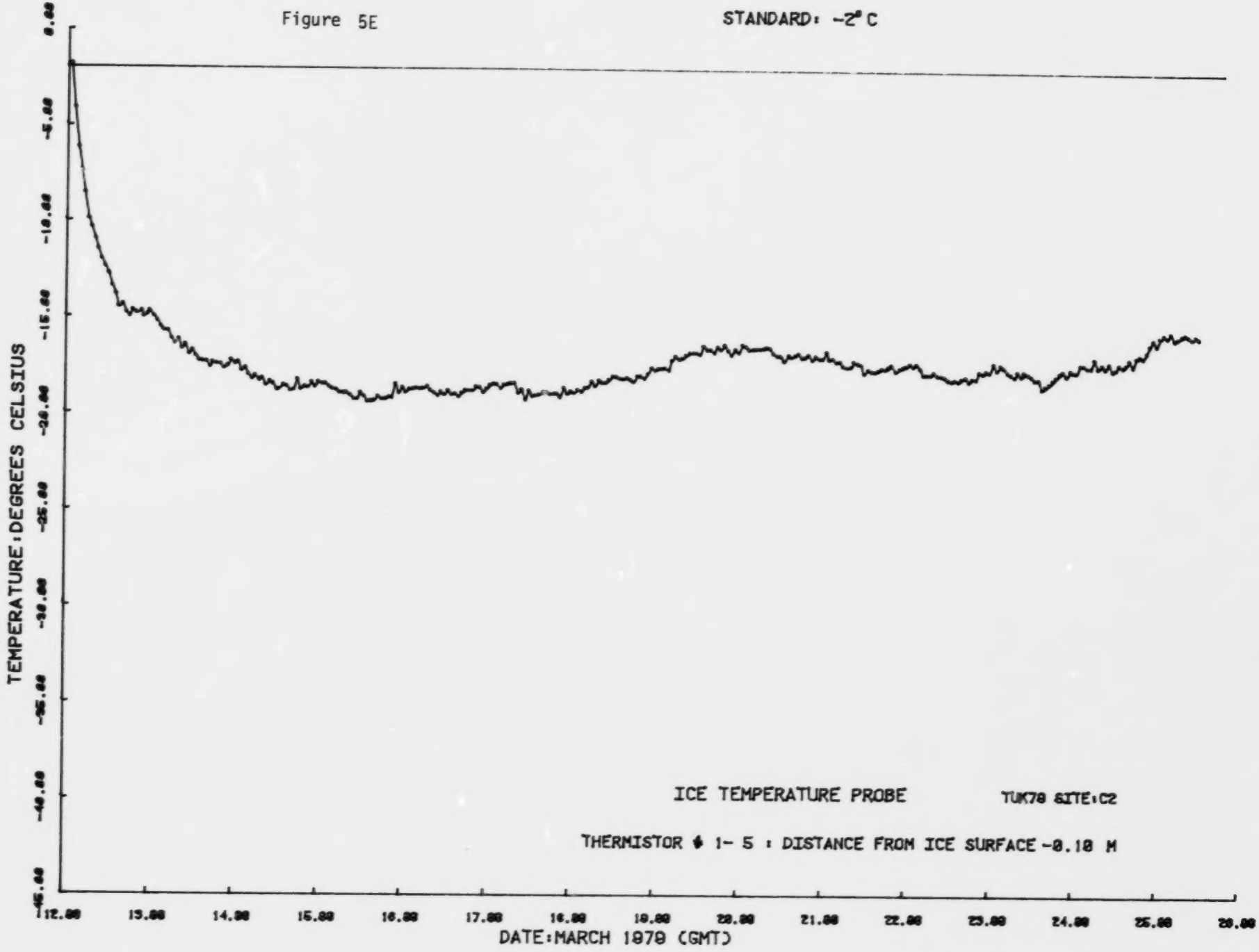

TEMPERATURE:DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK78 SITE:C2
THERMISTOR # 1- 5 : DISTANCE FROM ICE SURFACE -0.10 M
DATE:MARCH 1978 (GMT)

Figure 5F

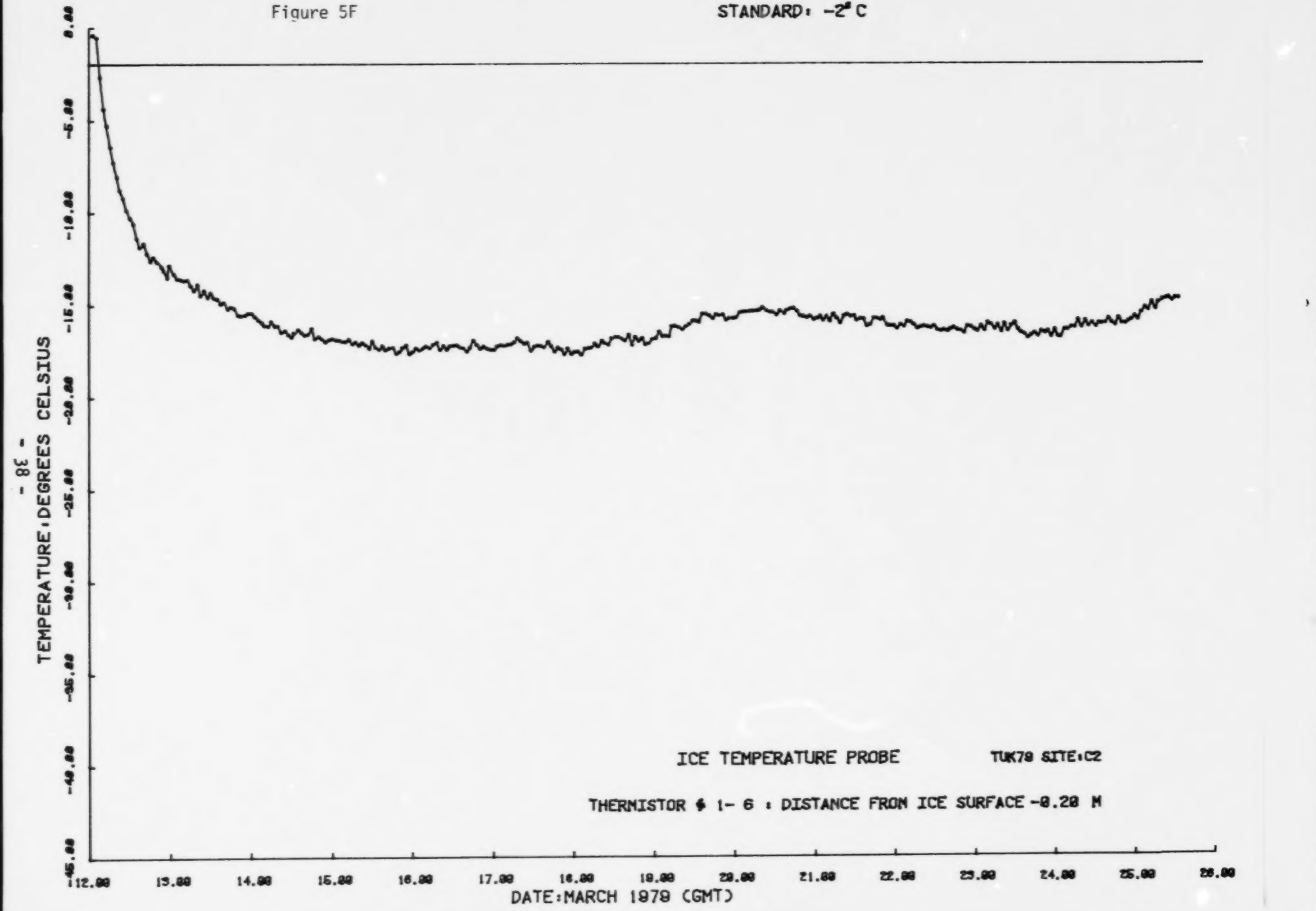

STANDARD: -2° C
TEMPERATURE:DEGREES CELSIUS
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
-45.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
19.00
20.00
21.00
22.00
23.00
24.00
25.00
26.00
DATE:MARCH 1978 (GMT)
ICE TEMPERATURE PROBE
TUK79 SITE:C2
THERMISTOR # 1- 6 : DISTANCE FROM ICE SURFACE -0.20 M

Figure 5G

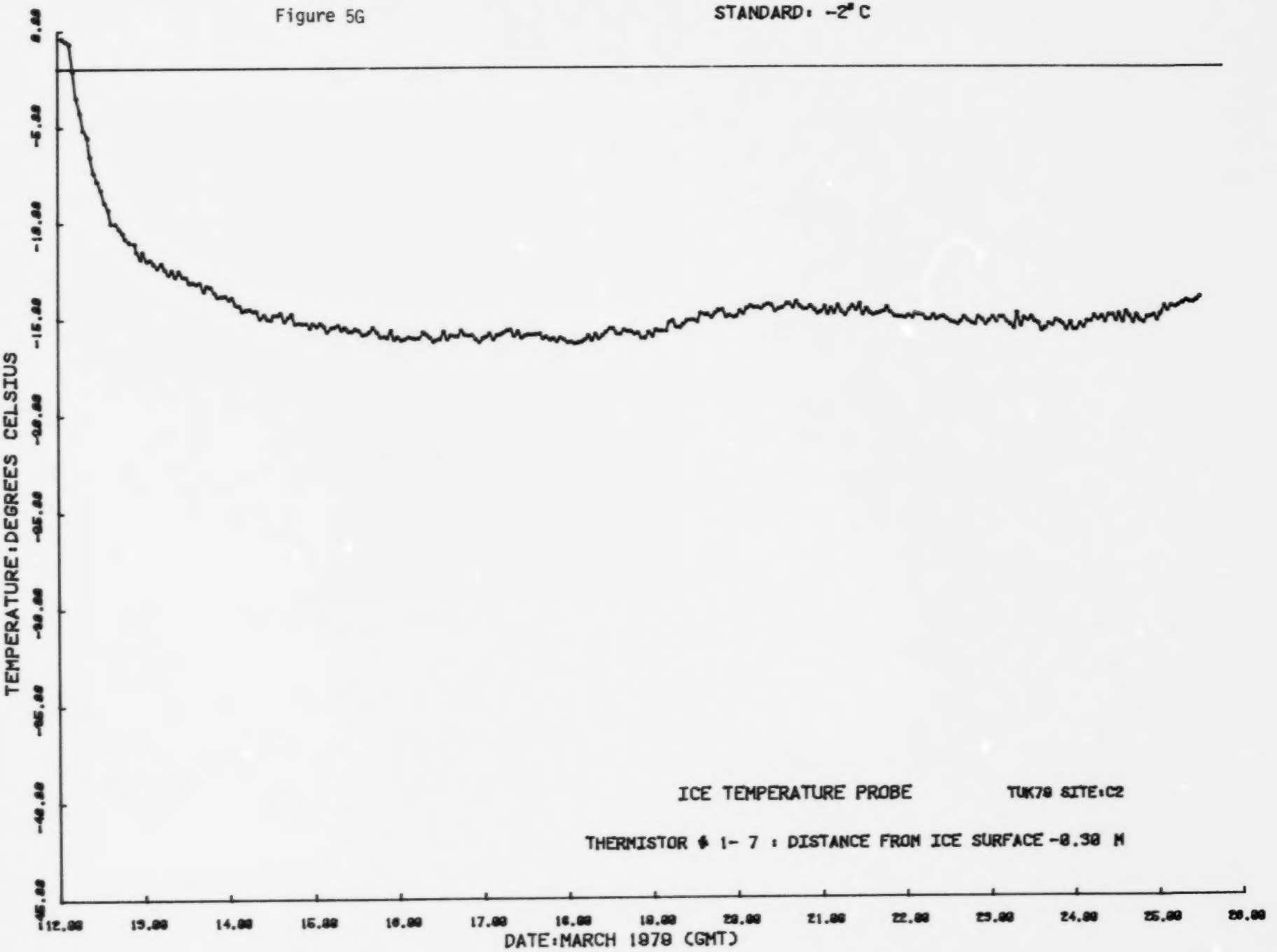

STANDARD: -2° C
TEMPERATURE:DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK79 SITE:C2
THERMISTOR # 1- 7 : DISTANCE FROM ICE SURFACE -0.30 M
12.00
13.00
14.00
15.00
16.00
17.00
18.00
19.00
20.00
21.00
22.00
23.00
24.00
25.00
26.00
DATE:MARCH 1979 (GMT)

Figure 5H

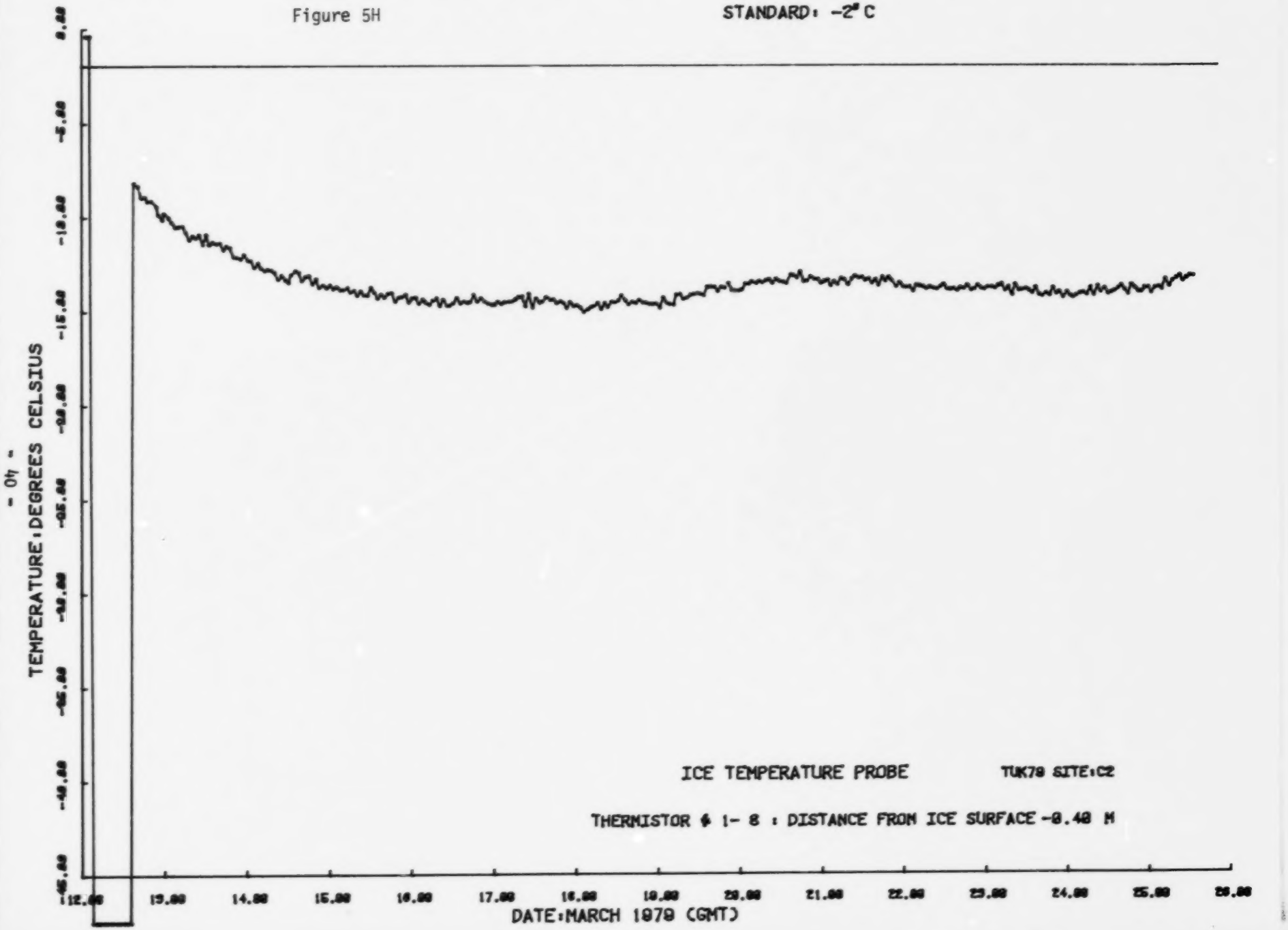

STANDARD: -2° C
TEMPERATURE: DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK79 SITE:C2
THERMISTOR # 1- 8 : DISTANCE FROM ICE SURFACE -0.40 M
DATE: MARCH 1979 (GMT)

Figure 5I

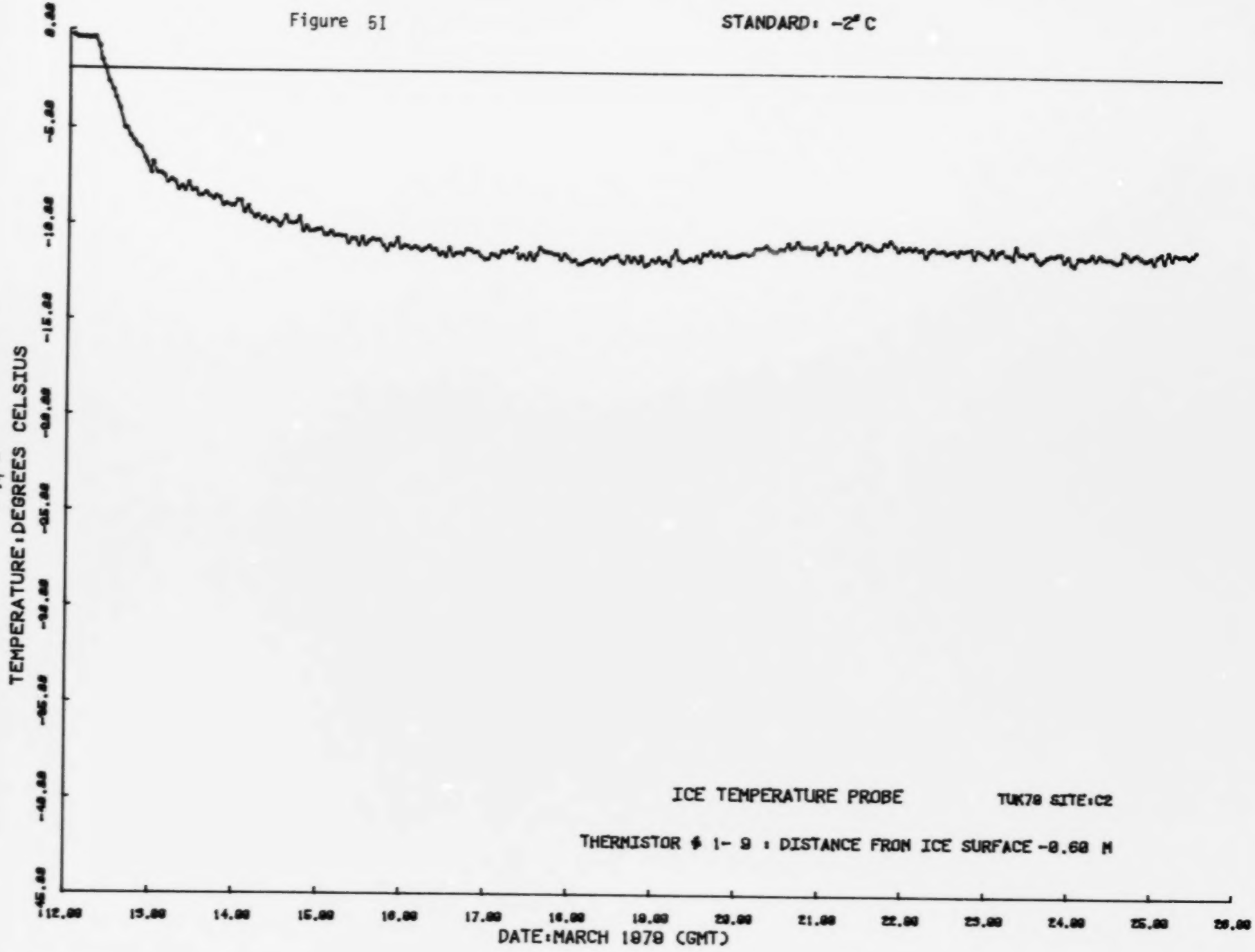

STANDARD: -2° C
TEMPERATURE:DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK78 SITE:C2
THERMISTOR # 1- 9 : DISTANCE FROM ICE SURFACE -0.60 M
DATE:MARCH 1978 (GMT)

Figure 5J

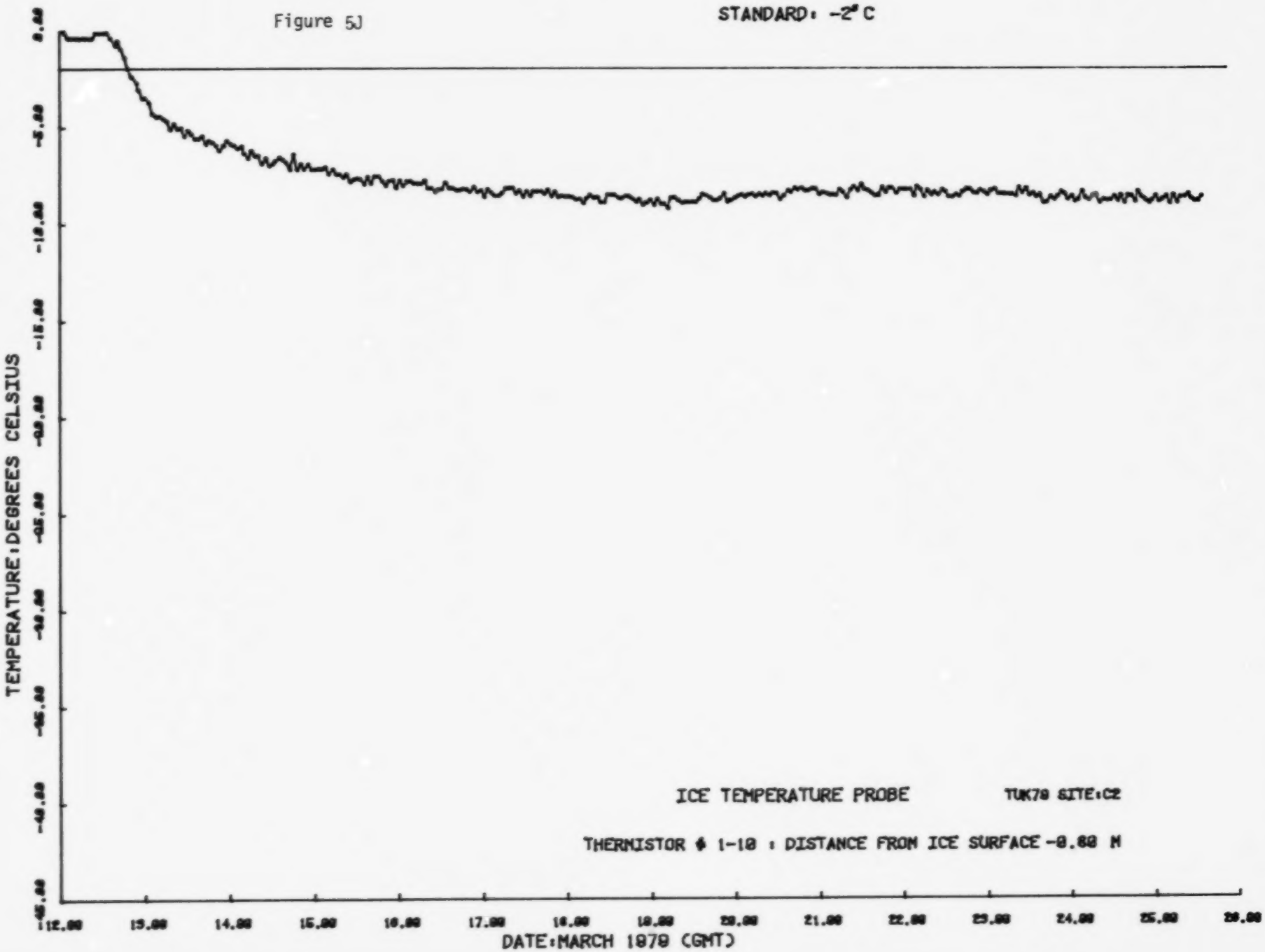

STANDARD: -2° C
TEMPERATURE:DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK79 SITE:C2
THERMISTOR # 1-10 : DISTANCE FROM ICE SURFACE -0.60 M
DATE:MARCH 1979 (GMT)

Figure 5K

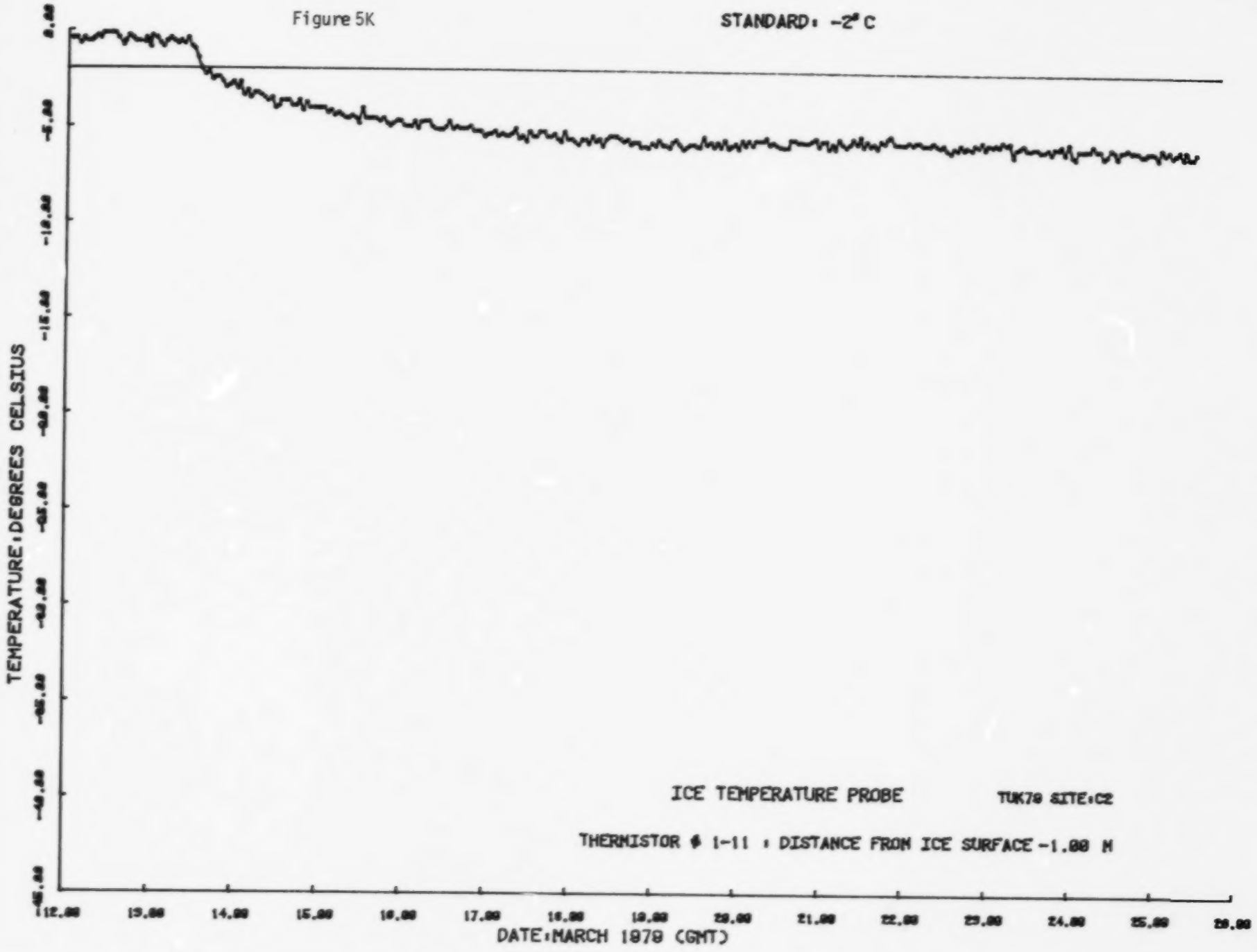

STANDARD: -2° C
TEMPERATURE: DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK79 SITE:C2
THERMISTOR # 1-11 : DISTANCE FROM ICE SURFACE -1.00 M
DATE: MARCH 1979 (GMT)

Figure 5L

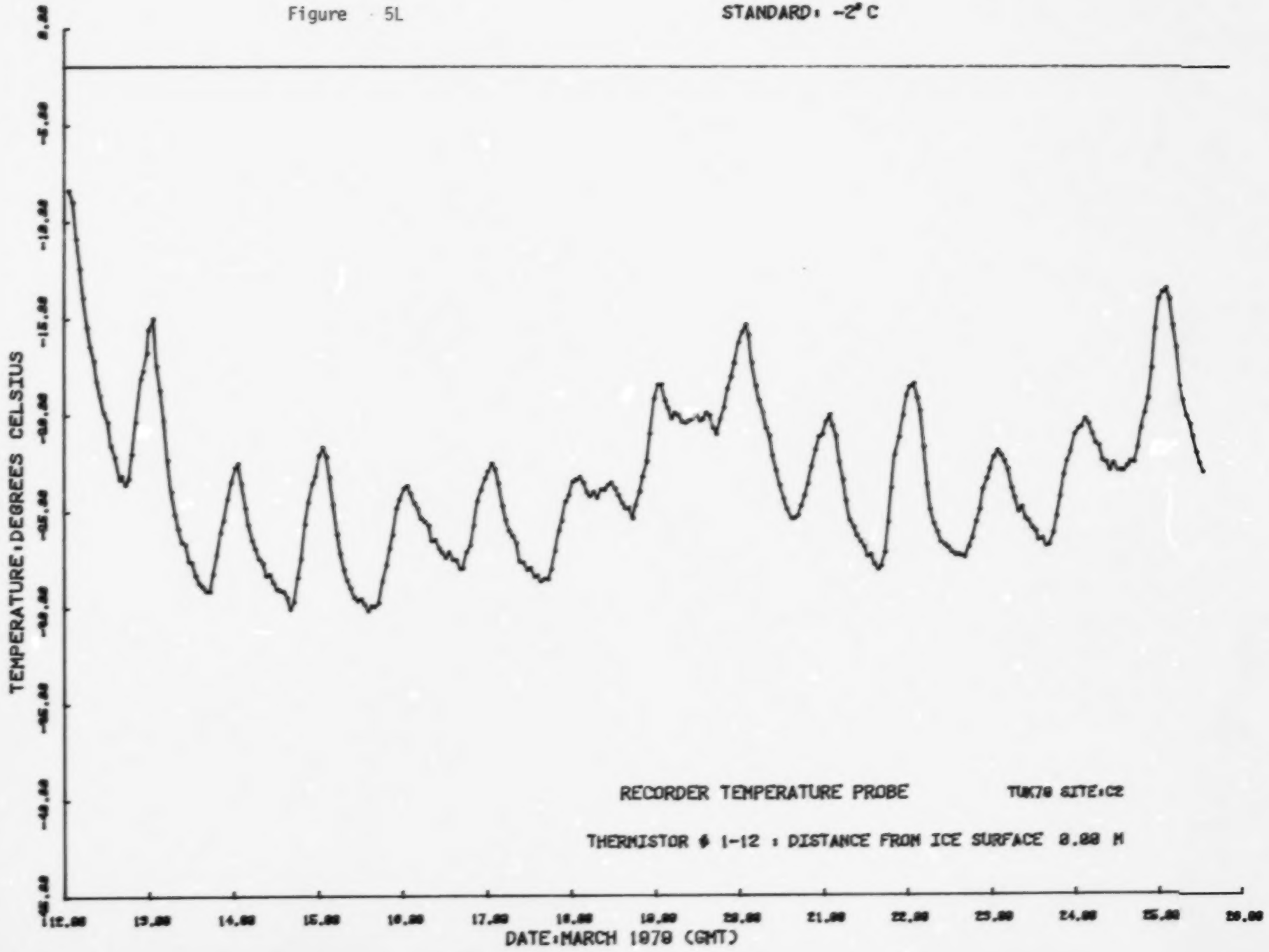

STANDARD: -2° C
TEMPERATURE: DEGREES CELSIUS
RECORDER TEMPERATURE PROBE
TUK78 SITE:C2
THERMISTOR # 1-12 : DISTANCE FROM ICE SURFACE 0.00 M
DATE: MARCH 1978 (GMT)

Figure 5M

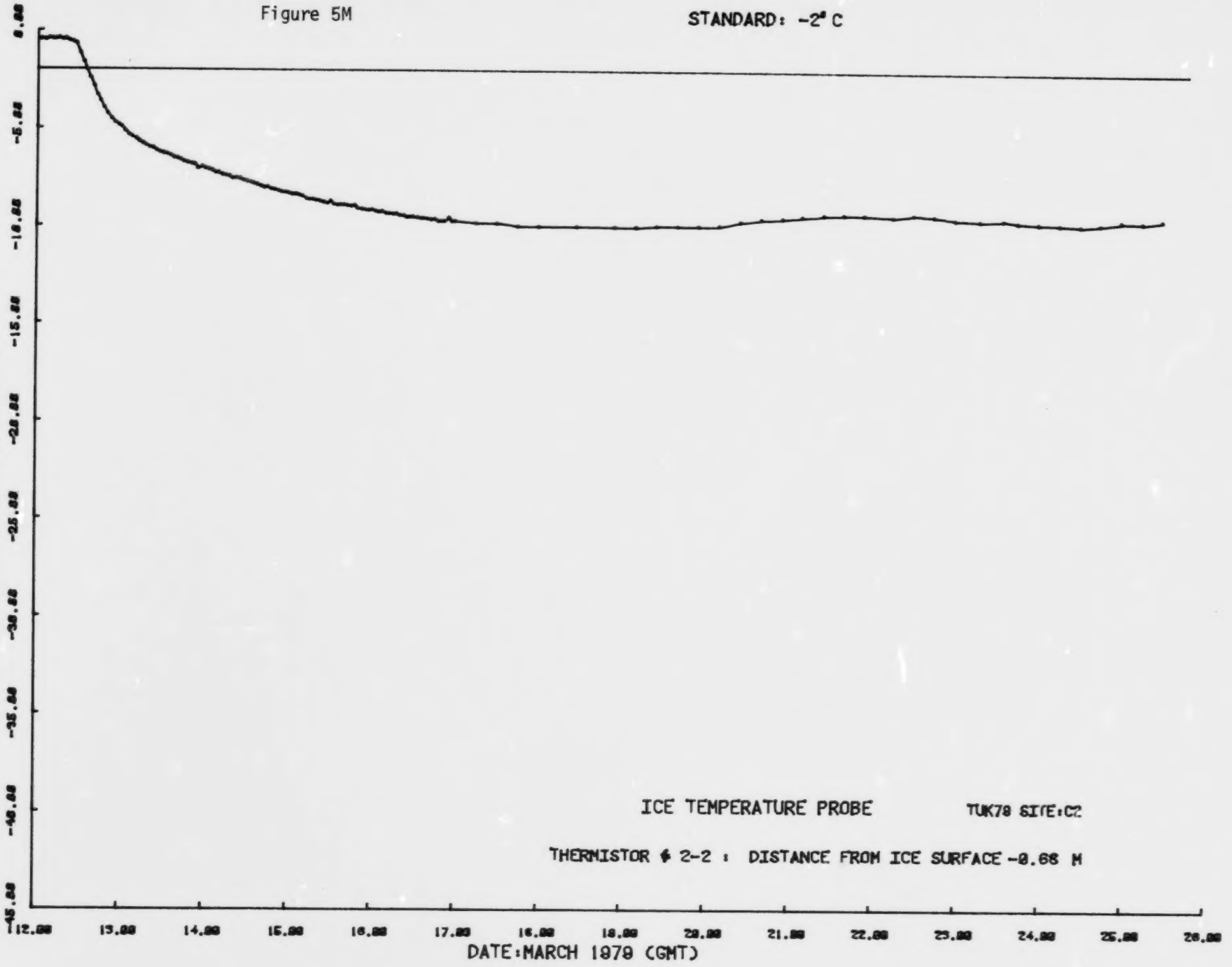

STANDARD: -2° C
TEMPERATURE: DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK78 SITE:C2
THERMISTOR # 2-2 : DISTANCE FROM ICE SURFACE -0.68 M
DATE:MARCH 1978 (GMT)

Figure 5N

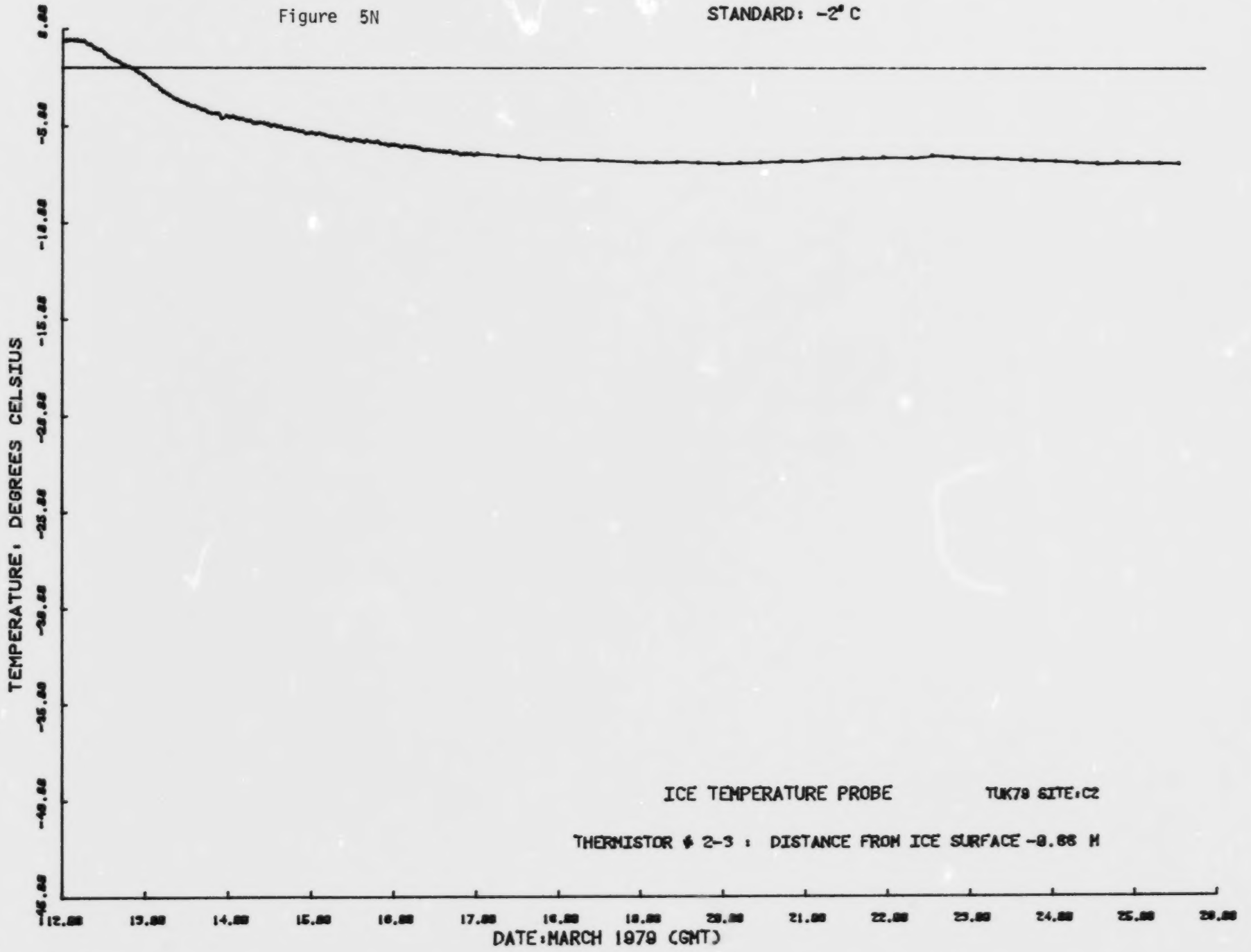

STANDARD: -2° C
TEMPERATURE: DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK79 SITE:C2
THERMISTOR # 2-3 : DISTANCE FROM ICE SURFACE -0.66 M
DATE:MARCH 1979 (GMT)

Figure 50

STANDARD: -2° C

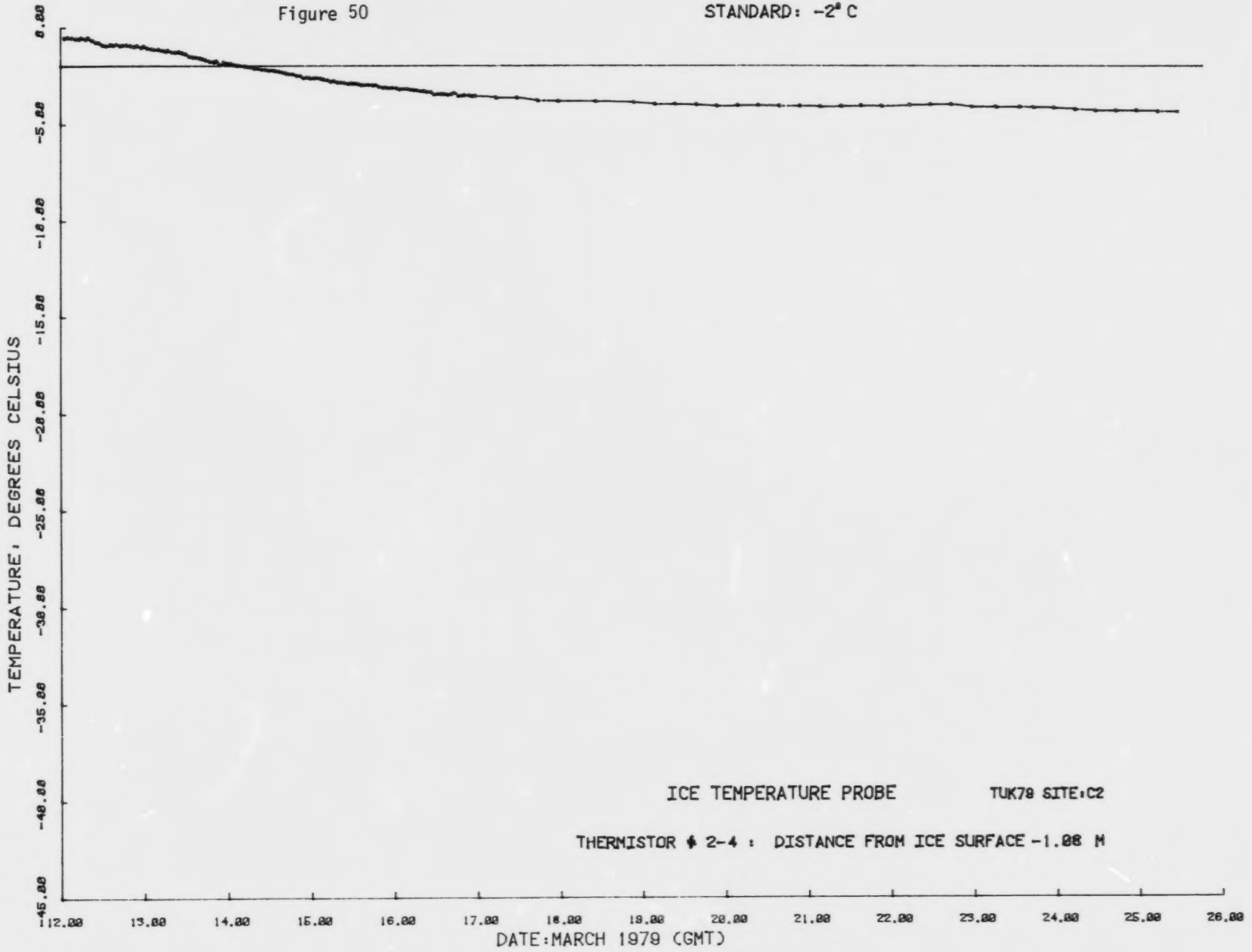


Figure 5P

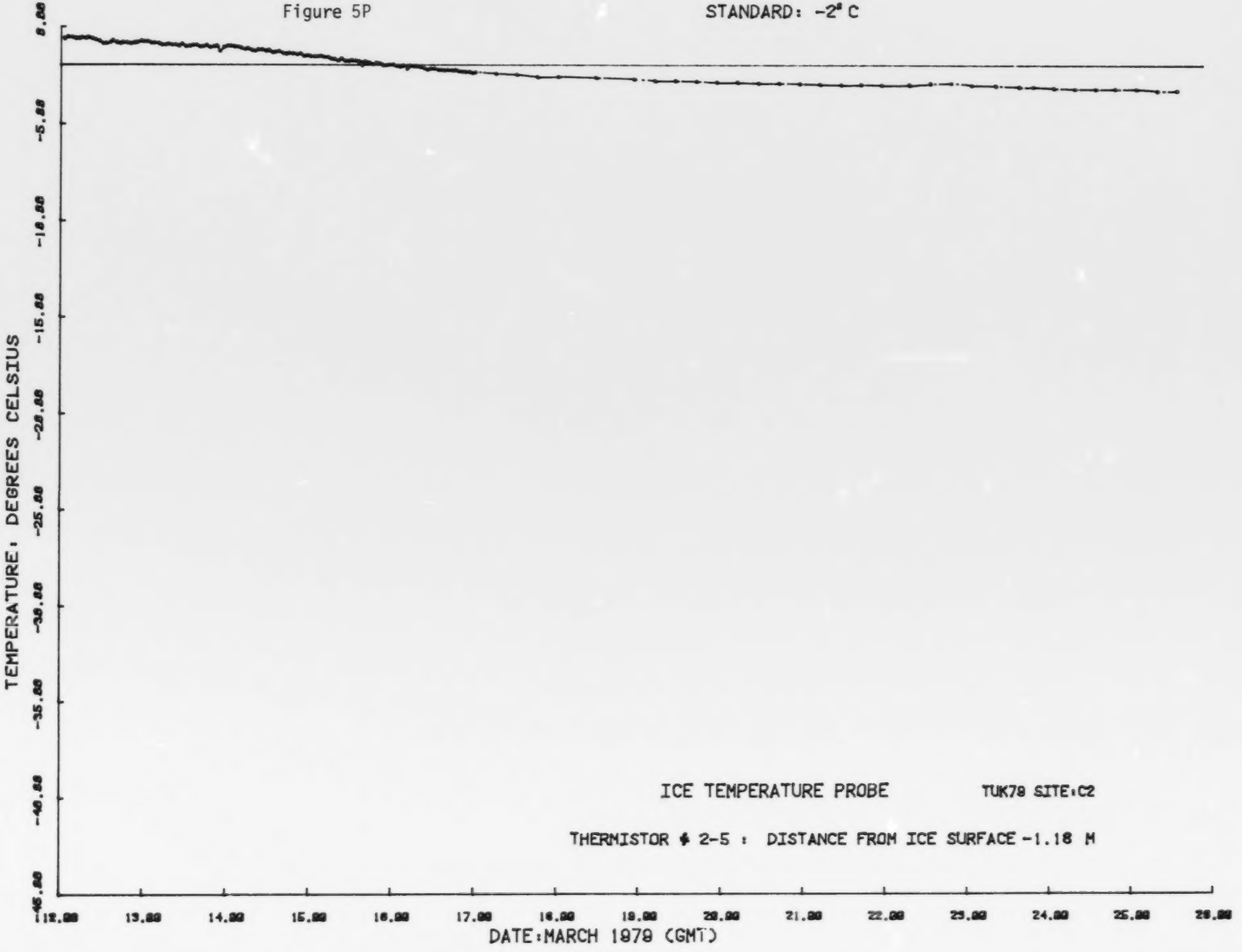

STANDARD: -2° C
TEMPERATURE: DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK78 SITE:C2
THERMISTOR # 2-5 : DISTANCE FROM ICE SURFACE -1.18 M
DATE:MARCH 1978 (GMT)

Figure 5Q

STANDARD: -2° C

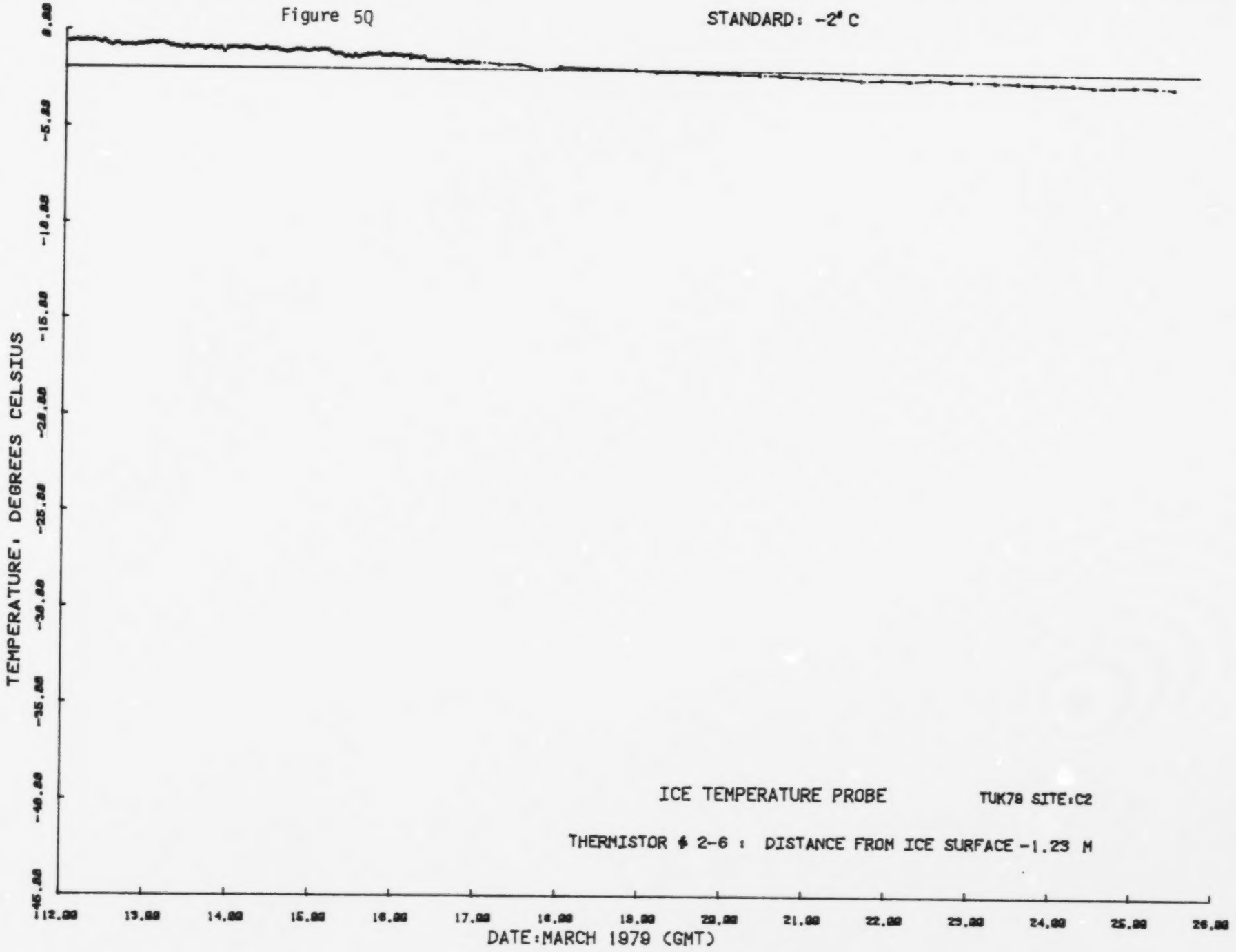


Figure 5R

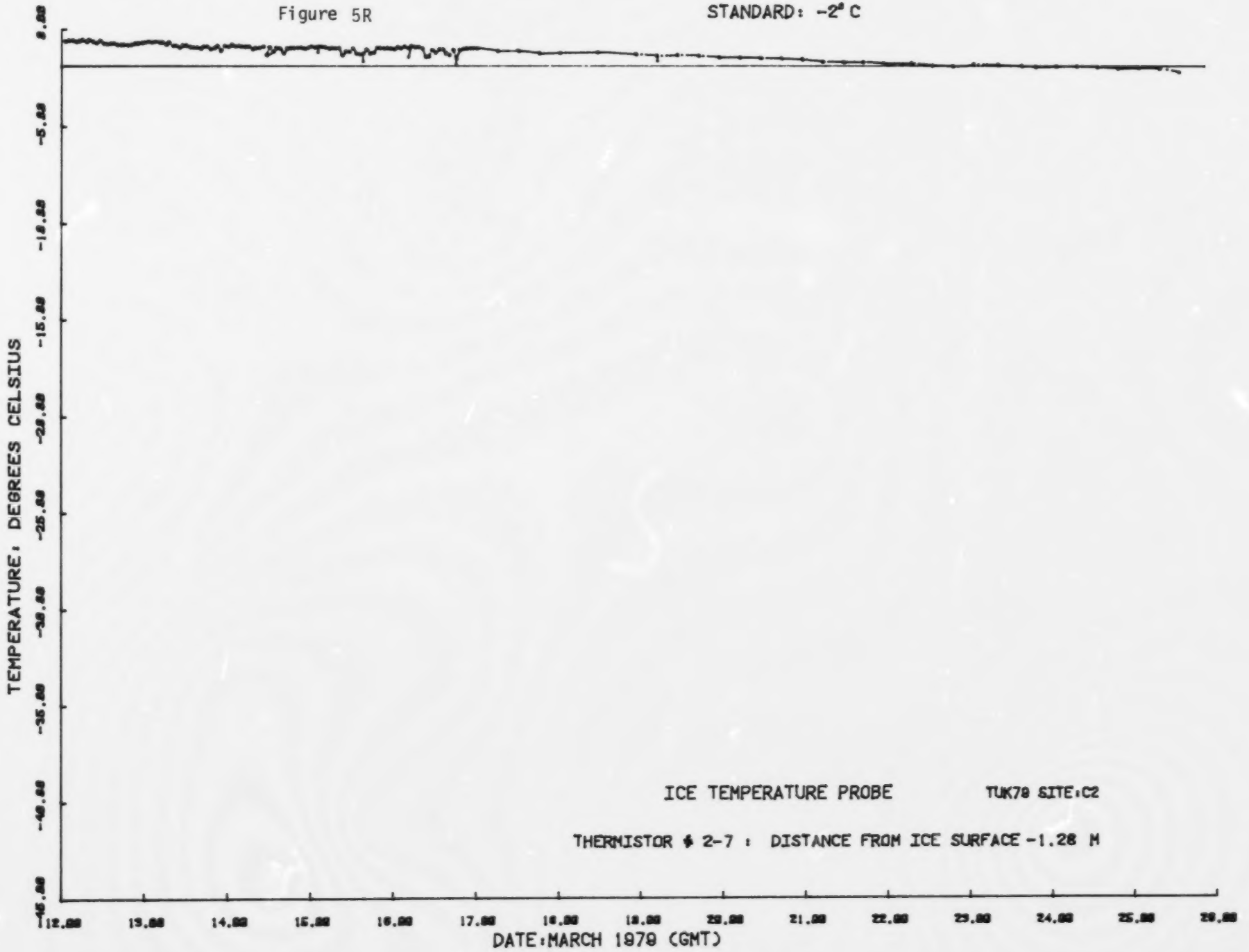

STANDARD: -2° C
TEMPERATURE: DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK79 SITE:C2
THERMISTOR # 2-7 : DISTANCE FROM ICE SURFACE -1.28 M
DATE:MARCH 1979 (GMT)

Figure 5S

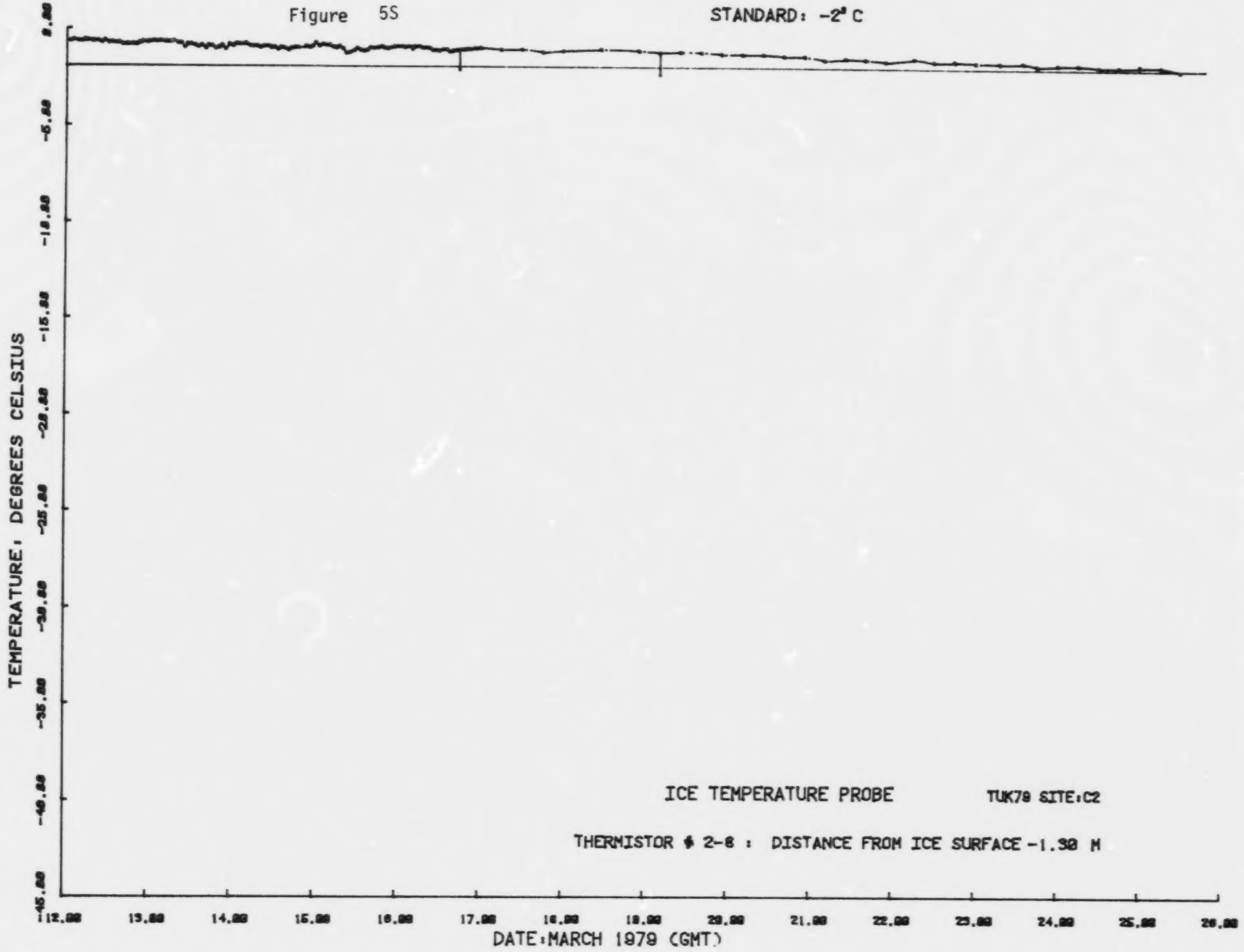

STANDARD: -2° C
TEMPERATURE: DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK79 SITE:C2
THERMISTOR # 2-8 : DISTANCE FROM ICE SURFACE -1.30 M
DATE:MARCH 1979 (GMT)

Figure 5T

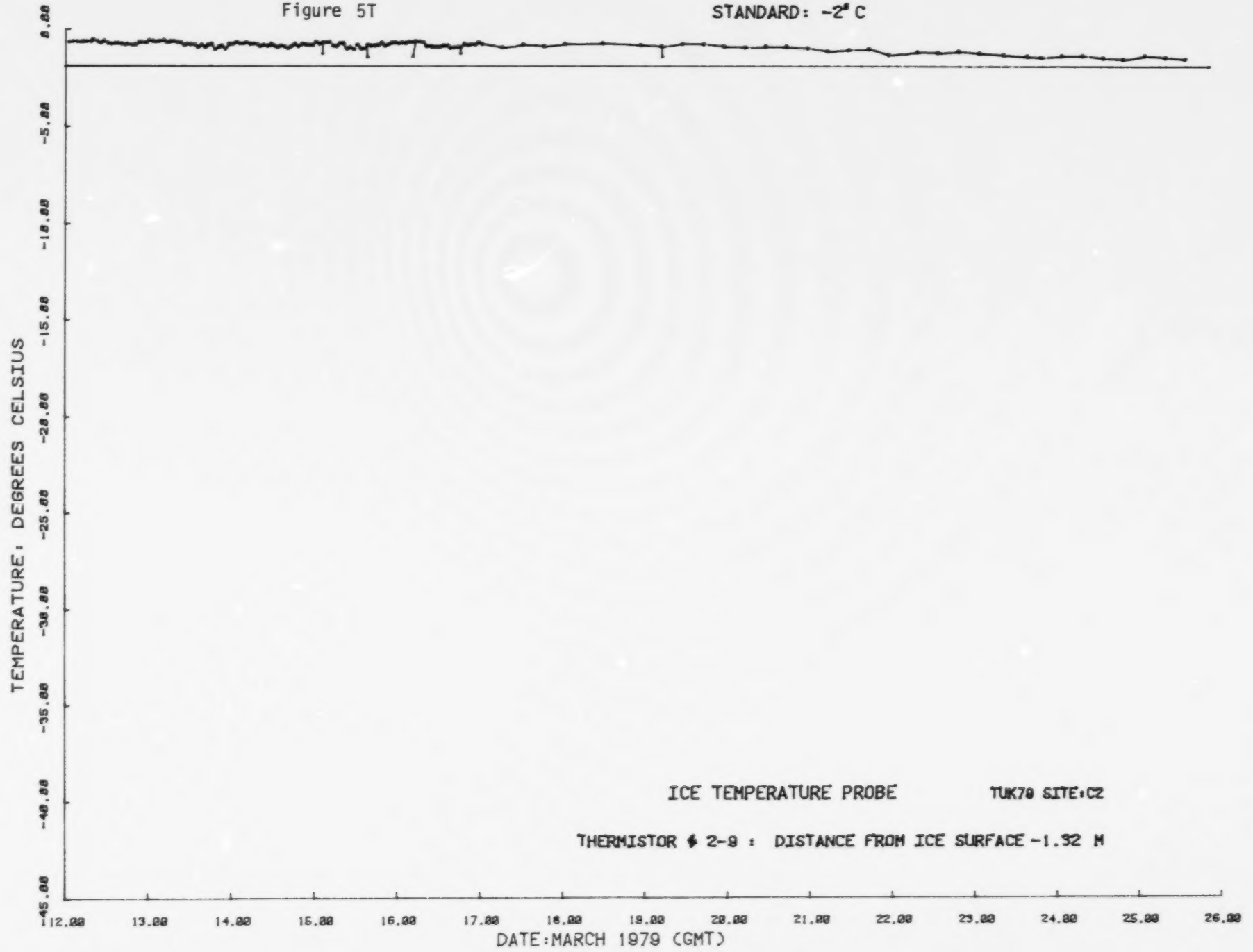

STANDARD: -2° C
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
-45.00
TEMPERATURE: DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK79 SITE:C2
THERMISTOR # 2-9 : DISTANCE FROM ICE SURFACE -1.32 M
12.00
13.00
14.00
15.00
16.00
17.00
18.00
19.00
20.00
21.00
22.00
23.00
24.00
25.00
26.00
DATE:MARCH 1979 (GMT)

Figure 5U

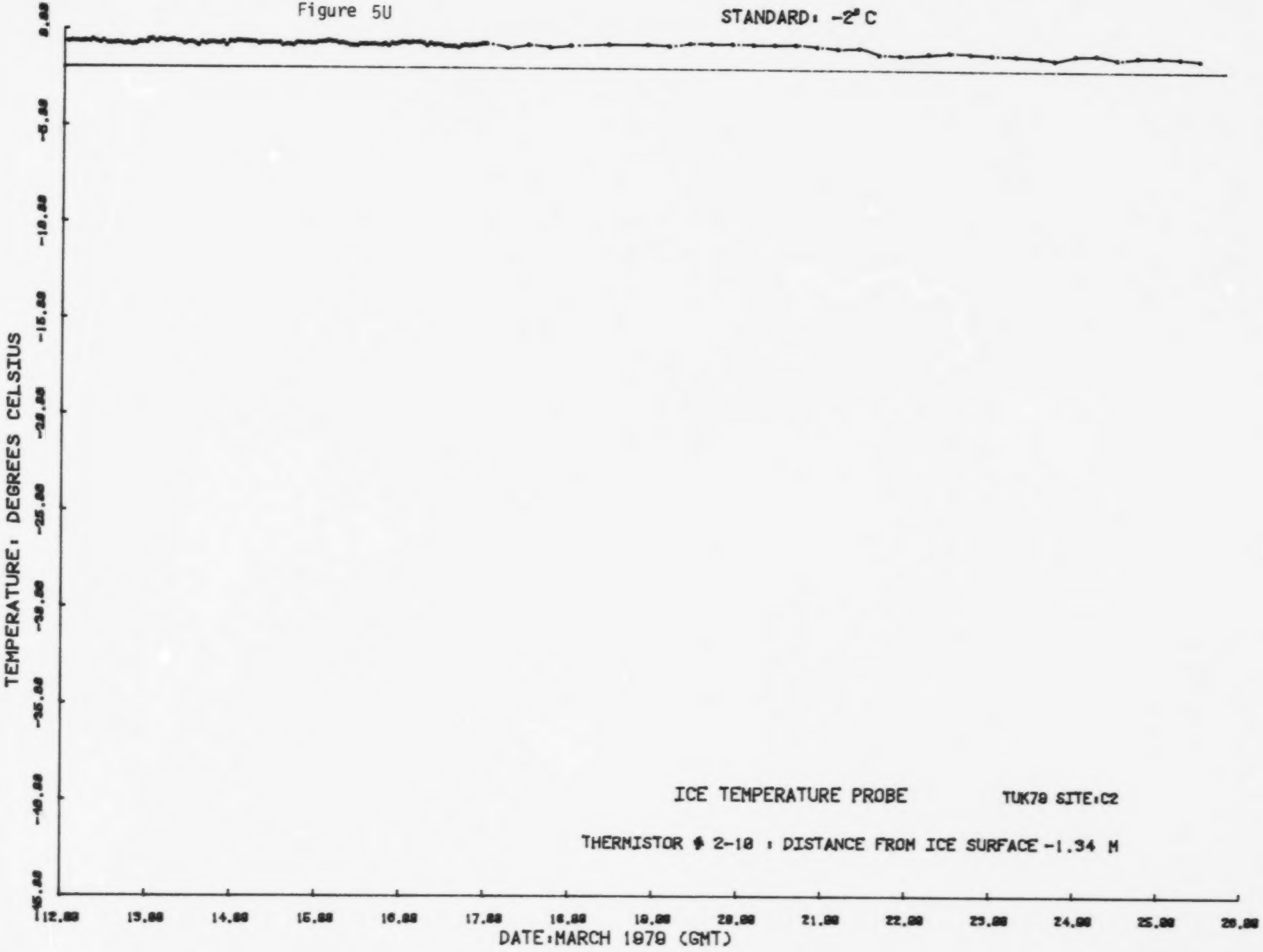

STANDARD: -2° C
TEMPERATURE: DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK78 SITE:C2
THERMISTOR # 2-10 : DISTANCE FROM ICE SURFACE -1.34 M
DATE:MARCH 1978 (GMT)

Figure 5V

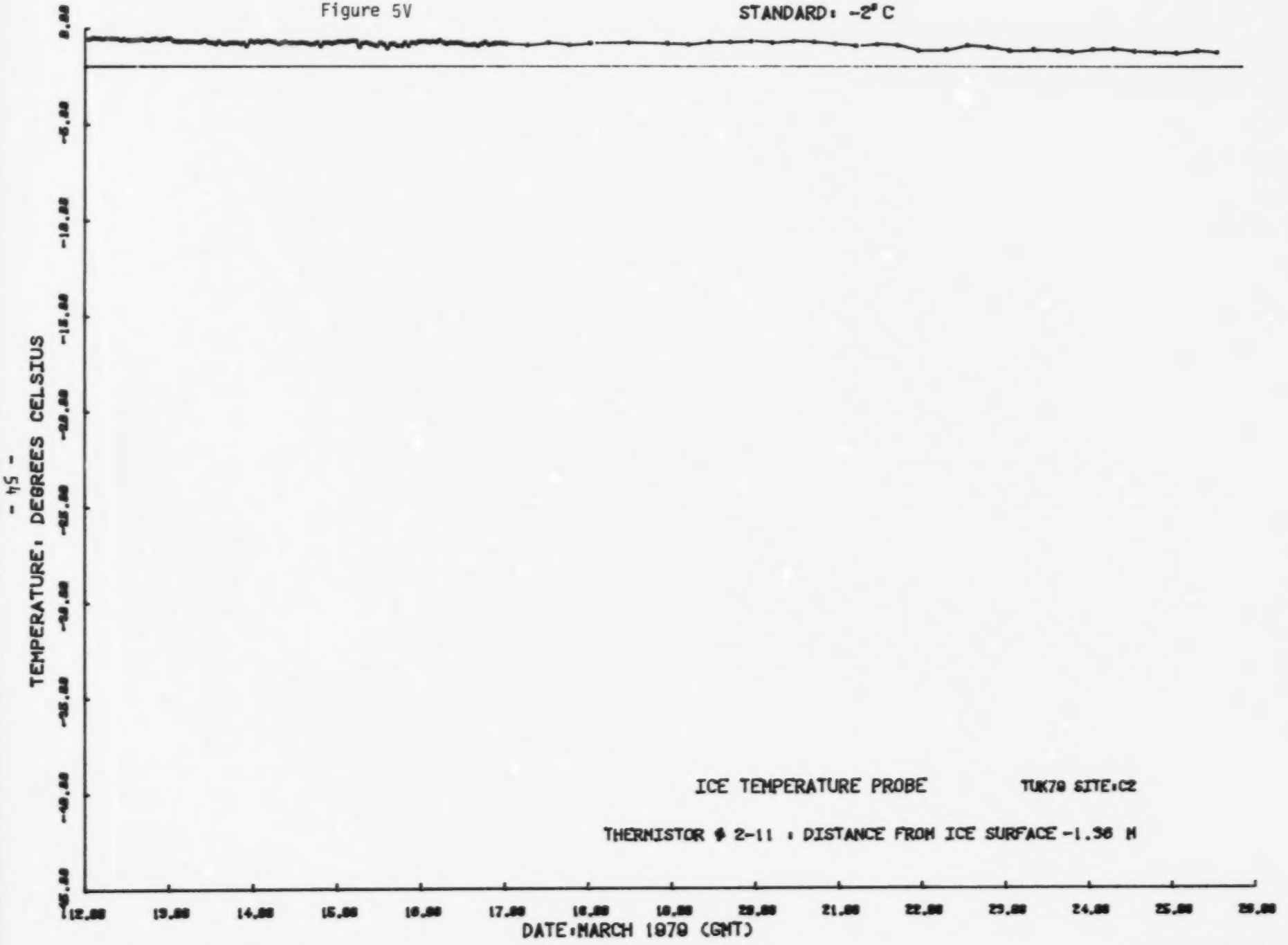

STANDARD: -2° C
TEMPERATURE: DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK79 SITE:C2
THERMISTOR # 2-11 : DISTANCE FROM ICE SURFACE -1.36 M
DATE:MARCH 1979 (GMT)

Figure 5W

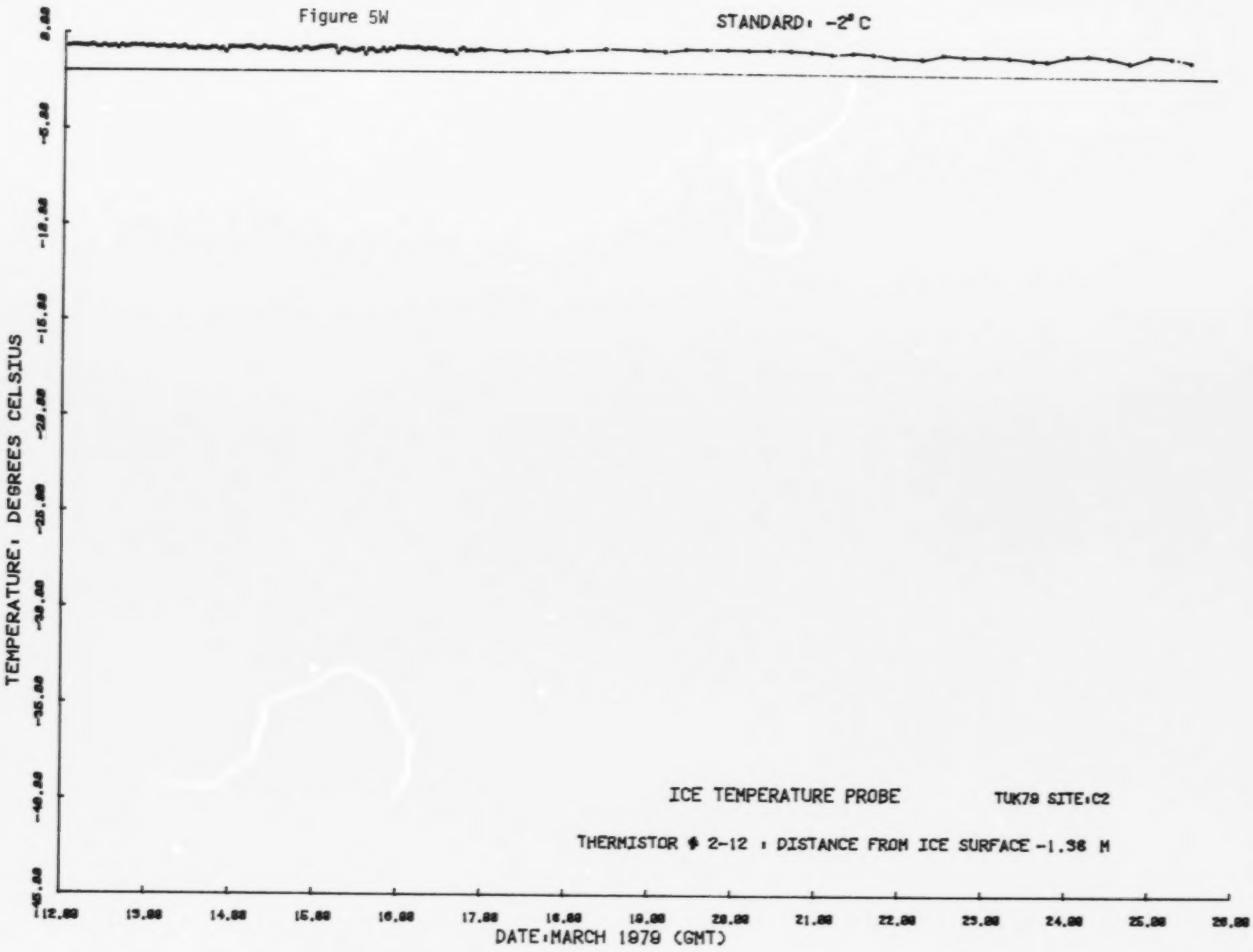
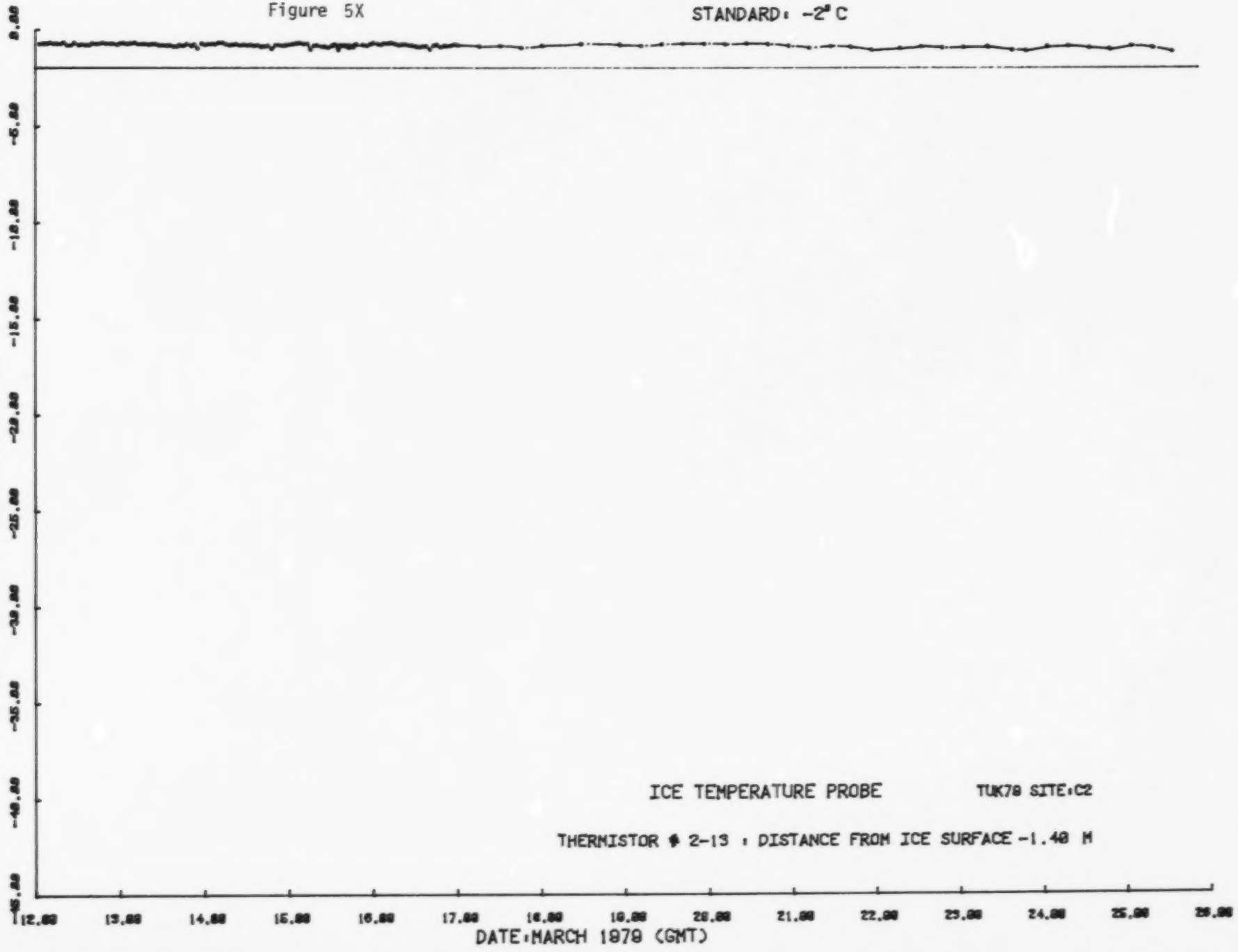

STANDARD: -2° C
TEMPERATURE: DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK79 SITE:C2
THERMISTOR # 2-12 : DISTANCE FROM ICE SURFACE -1.38 M
DATE:MARCH 1979 (GMT)

Figure 5X


STANDARD: -2° C
TEMPERATURE: DEGREES CELSIUS
ICE TEMPERATURE PROBE
TUK78 SITE:C2
THERMISTOR # 2-13 : DISTANCE FROM ICE SURFACE -1.40 M
DATE:MARCH 1978 (GMT)

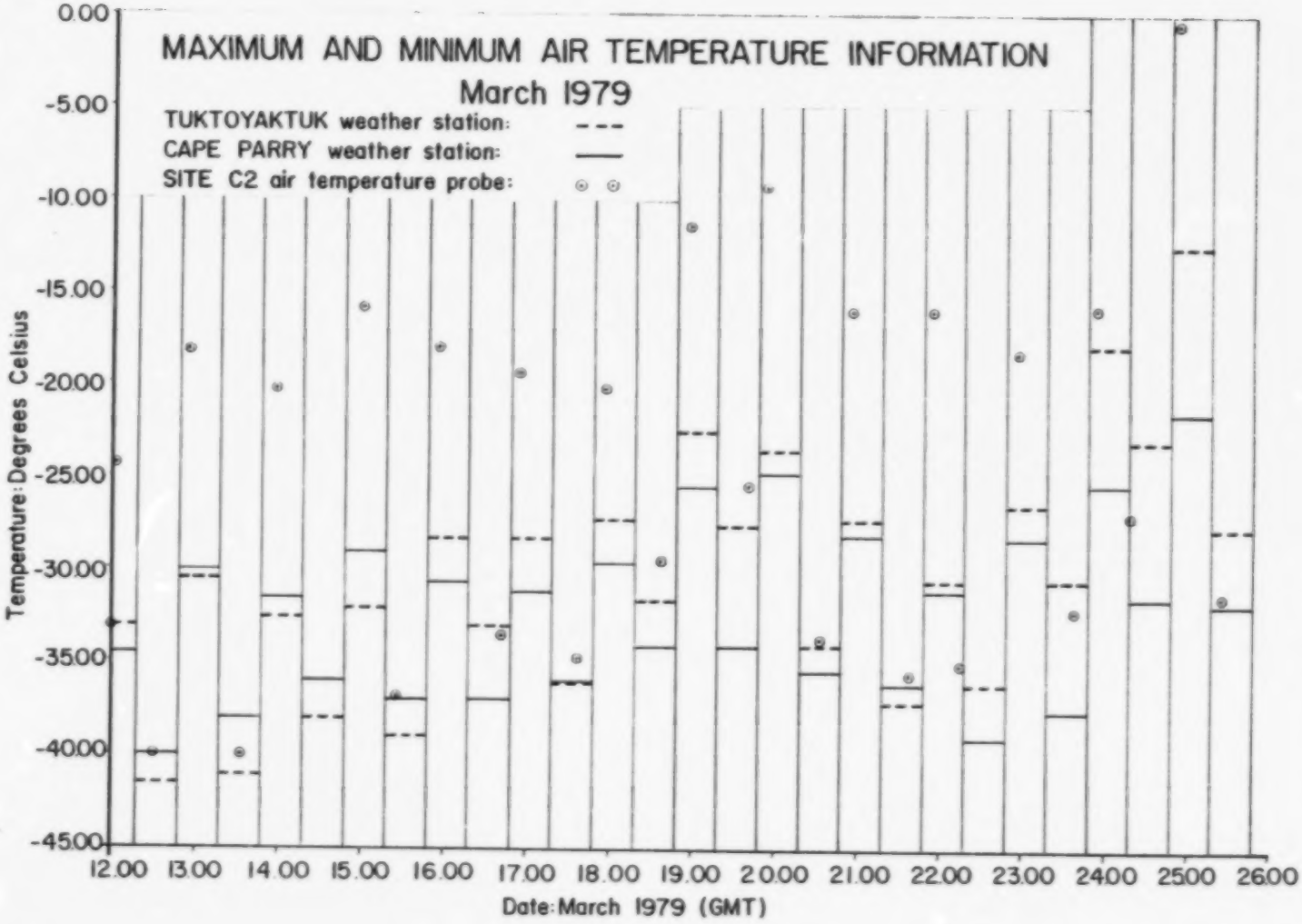

MAXIMUM AND MINIMUM AIR TEMPERATURE INFORMATION
March 1979
TUKTOYAKTUK weather station:
CAPE PARRY weather station:
SITE C2 air temperature probe:
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
-45.00
Temperature: Degrees Celsius
12.00
13.00
14.00
15.00
16.00
17.00
18.00
19.00
20.00
21.00
22.00
23.00
24.00
25.00
26.00
Date: March 1979 (GMT)

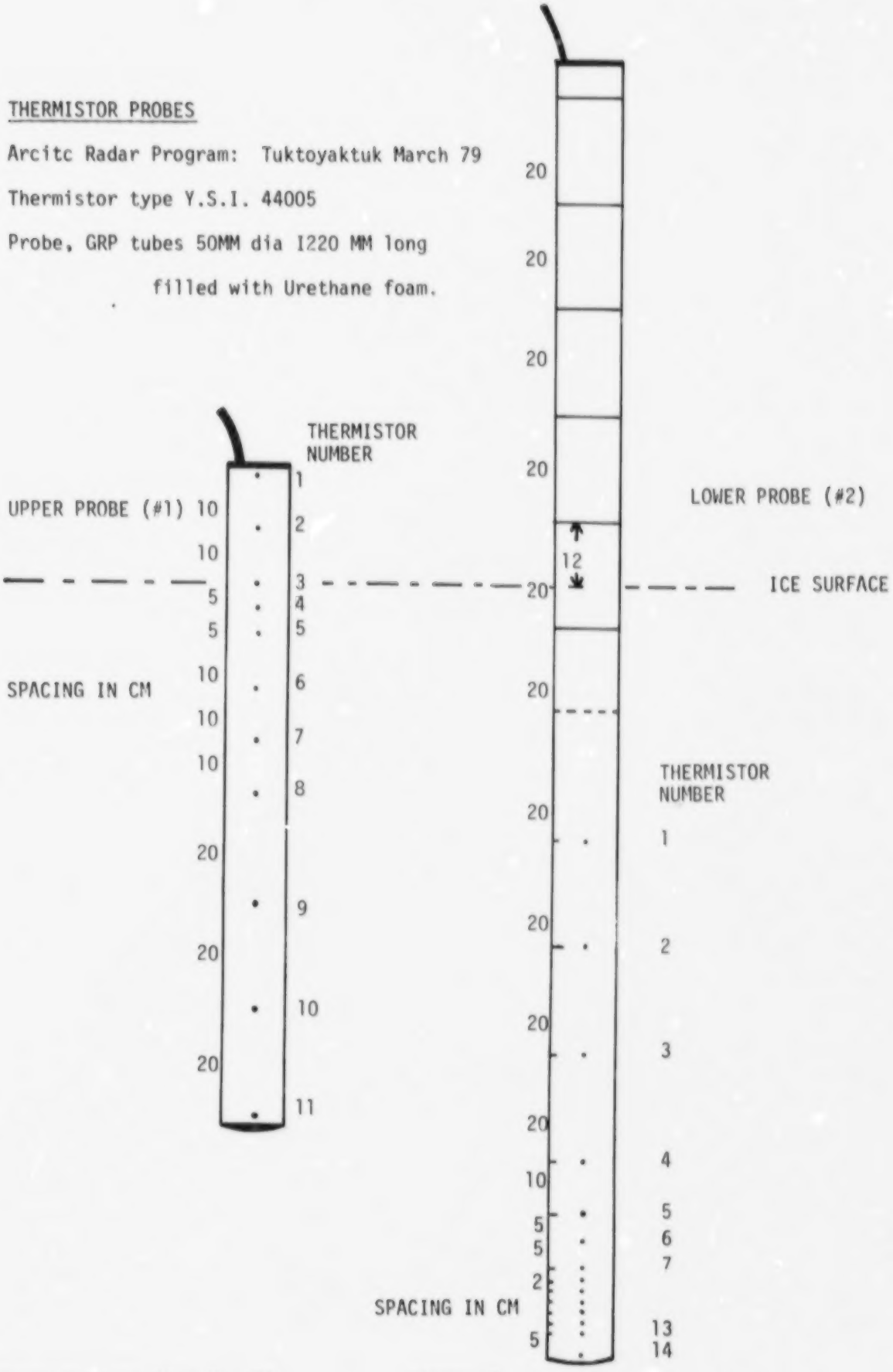
Figure 6

THERMISTOR PROBES

Arcitc Radar Program: Tuktoyaktuk March 79

Thermistor type Y.S.I. 44005

Probe, GRP tubes 50MM dia I220 MM long
filled with Urethane foam.



Terry Ridings 30th May 79

Figure 7

THERMISTOR PROBES

Arctic Radar Program: Tuktoyaktuk March 79

Recording package: RUSTRAK Chart Recorder model 388, 2 Channel
In house designed and built electronics
2 X 16 channel multiplexer with bridge system

NOTE "Instrument Thermistor" located inside RUSTRAK Recorder

SURFACE PROFILE (probe #1) $-50^{o} \rightarrow +5^{o}C$

CHANNEL	#1	=	$-60^{o}C$ (fixed resistor)
	#2	=	$-2^{o}C$ " "
	#3	=	DATA
	#13	=	
	#14	=	not in use
	#15	=	" " "
	#16	=	Recording Instrument Temperature

BOTTOM PROFILE (probe #2) -10^{o} $0^{o}C$

CHANNEL	#1	=	$-15^{o}C$ (fixed resistor)
	#2	=	$-2^{o}C$ " "
	#3	=	DATA
	#16	=	

Specifications to accompany Figure 7

Terry Ridings 30th May 79

Graph for Conversion from Uncorrected to Corrected
Temperature for Upper Thermistor Probe

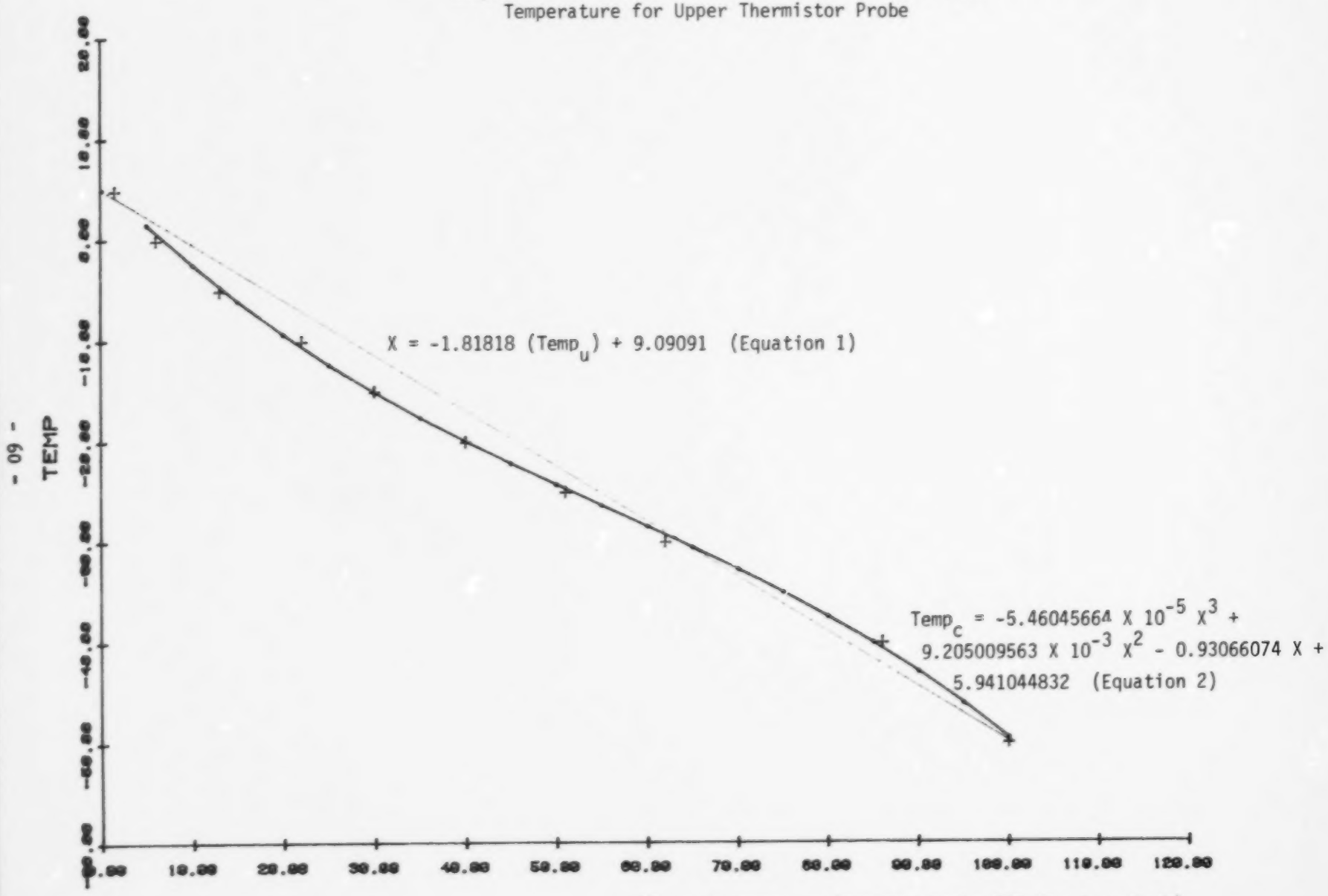


Figure 8

day and night; and that the snow layer reduced the amplitude of the temperature cycles arriving at the ice surface by about 80% and delayed the cycles in time by about 9 hours. These graphs also formed the data base for analysis of a natural high temperature impulse travelling through the ice sheet and analysis of ice growth in the auger hole (discussed below).

The thermistor recording the air temperature was not shaded from direct sunlight and the resulting solar heating caused unrealistically high daytime temperatures (maxima on the air temperature graph). The minima of the air temperature graph are quite realistic, and represent the night-time air temperatures at site C2. Figure 6 shows a comparison between the site C2 air temperatures and the maximum/minimum air temperature information from Tuktoyaktuk and Cape Parry Weather Stations.

Processing of the Recorded Temperature Data

The temperature data were recorded by a RUSTRAK Chart Recorder onto a chart roll. Two channels of multiplexed temperature information were recorded, one channel corresponding to the upper probe and one channel corresponding to the lower probe (Figure 7). The temperature information included 'fixed temperatures' from fixed resistors and actual temperatures from thermistors. The recorder was designed to update the temperature information once an hour, but due to the cold, the clocking cycle of the recorder sped up by a factor of 4, giving updates every 15 minutes. A very high information density resulted on the chart roll.

The temperature log was taken from chart rolls using a digitizing plotter. Every fourth cycle was digitized to give hourly data as planned, except for the lower probe data where the digitizing interval was increased to one point every six hours to speed up the digitizing process. The digitizing routine assumed a linear relationship between deflection on the chart

roll and temperature. The actual relationship of deflection on the chart roll versus temperature for the upper probe was determined in a cold room calibration experiment. The resulting calibration graph, fitted to a least squares polynominal of order three, is shown in Figure 8. The non-linearity was corrected for before the temperature graphs for the upper probe were re-plotted. For the lower probe no such correction was made due to the limited temperature range.

A second correction had to be made to the data due to the temperature dependence of the recording system electronics. As can be seen in Figure 9, the temperature from the fixed resistor labelled STANDARD -2° C was not constant. The range of the temperature cycles is -2.6° C $\pm$ 0.8° C, including approximately $\pm$ 0.35° C random fluctuations. The temperature dependence of the recording electronics becomes evident when the -2° C STANDARD is correlated with the RECORDER TEMPERATURE. To compensate for this temperature dependence, each of the data points was corrected with the corresponding offset from -2° C for that hour.

There are errors inherent in the processing of temperature information by recording on a strip chart recorder and digitizing with a plotter-digitizer. To estimate these errors, the temperature graphs were analysed. Comparison between Figures 5 I (-0.6 m) and 5 J (-0.68 m) shows that the small scale temperature fluctuations observed on Figure 5 I are not actual temperature variations, but random errors due to the data processing. This average random error was measured to be $\pm$ 0.5° C for the upper probe and $\pm$ 0.2° C for the lower probe. The average random error in the temperature graphs is the result of two processing errors. The data digitized from the RUSTRAK chart contains random errors of $\pm$ 0.35°C and $\pm$ 0.14° C for the upper and lower probes respectively, but

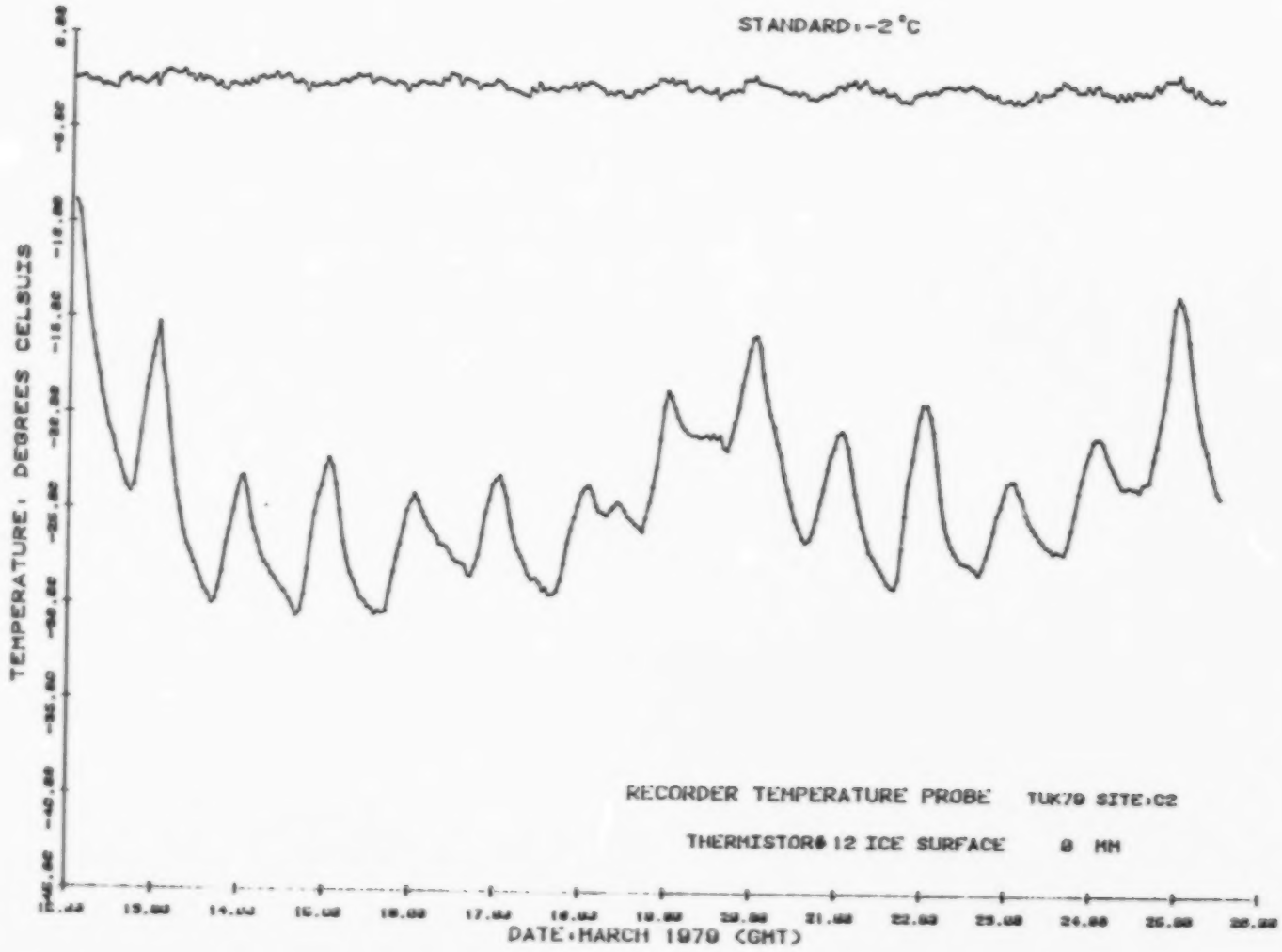

STANDARD: -2 °C
TEMPERATURE: DEGREES CELSIUS
RECORDER TEMPERATURE PROBE TUK79 SITE:C2
THERMISTOR# 12 ICE SURFACE 0 MM
DATE: MARCH 1979 (GMT)

Figure 9

the correction for temperature dependence increases these errors. The standard resistance trace used for this correction was processed as data, therefore it contains the same basic random processing error, thus the increase in the total error is by a factor of $\sqrt{2}$.

Sources of error in the digitizing are the plotter and the operator. The specified plotter accuracy is $\pm$ 0.01 inches and the estimated accuracy of reproducing a single point using a human operator is $\pm$ 0.03 inches. These errors give rise to a possible processing error of $\pm$ 0.8° C for the upper probe and $\pm$ 0.2° C for the lower probe. This corresponds very well to the errors measured from the data. An additional error affecting the validity of the final data is the tolerance of the thermistors, specified as $\pm$ 0.2° C.

Time Behaviour of a Heat Impulse

Close examination of the set of temperature graphs showed that the period of high air temperatures, lasting from approximately March 18.71 to March 20.71 (GMT) 1979, produced distinguishable effects in the ice sheet temperatures as far as 0.9 metres below the ice surface. This impulse of heat was traced by sketching a curve through each temperature record, visually detecting the peak and recording the depth, temperature and time associated with the peak (Table 11). A plot of the peak temperatures against depth is shown in Figure 19 together with an ice temperature profile obtained before the period of high temperature occurred (March 17.50). The peak temperatures are taken from different ice temperature profiles at different times, therefore only a limited comparison is possible with the baseline profile. The baseline and the peak temperature graphs cross over, which is due to the ice growth (discussed later) during the

Table 11

Baseline Profile and Peak Temperatures

Baseline Profile			Peak of High Temperature "Wave"		
Distance from ice surface (m)	Temperature (°C)	Time (decimal days)	Temperature (°C)	Time (decimal days)	
0.2	-34.0	17.5	-21.8	19.35	
0.1	-24.8	17.5	-19.8	19.57	
0	-20.7	17.5	-17.3	19.73	
-0.05	-19.7	17.5	-16.9	19.80	
-0.1	-19.0	17.5	-16.4	20.03	
-0.2	-17.2	17.5	-15.2	20.33	
-0.3	-15.9	17.5	-14.2	20.17	
-0.4	-14.9	17.5	-13.2	20.83	
-0.6	-11.9	17.5	-11.0	21.38	
-0.68	-9.9	17.5	-9.4	21.73	
-0.80	-8.5	17.5	-8.2	22.11	
-0.88	-6.6	17.5	-6.6	22.50	
-1.00	-5.4	17.5	no peak detected due to noise in trace		
-1.08	-3.7	17.5	-4.0	22.75	questionable
-1.18	-2.5	17.5	-2.9	22.79	differs by only 0.1°C from adjacent values.
-1.23	-1.8	17.5			
-1.28	-1.2	17.5			
-1.30	-1.1	17.5			
-1.32	-0.9	17.5			
-1.34	-0.8	17.5			

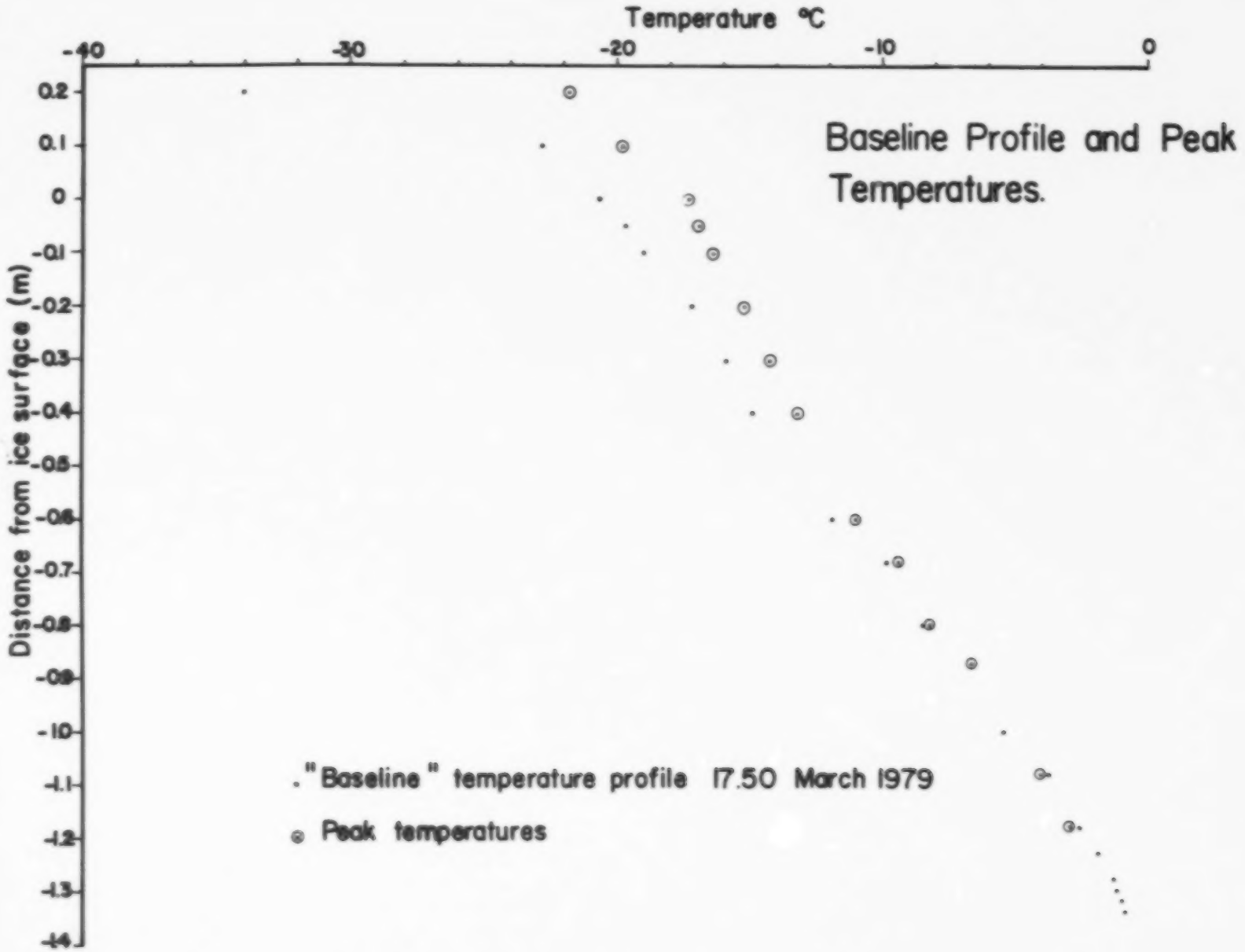

Temperature °C
-40
-30
-20
-10
0
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
Distance from ice surface (m)
Baseline Profile and Peak Temperatures.
."Baseline" temperature profile 17.50 March 1979
Peak temperatures

Figure 10

approximately 5 days elapsed between the baseline profile and the peak values near -0.9 metre from the surface.

The times of occurrence of the peak temperatures were also plotted against depth (Figure 11). The resulting graph fits well to a straight line, from the ice surface to -0.88 m. The random error in the data of the thermistor at -1.0 m precluded detection of a peak, and the peak values at -1.08 and -1.18 m were not measured with any confidence. The equation of the least squares straight line is $d = -0.32712\ t + 6.44072$, and the correlation coefficient is 0.99.

The slope represents the speed with which the impulse of heat travelled through the ice sheet (0.327 m/day). The thermal diffusivity was calculated using the equation for depth of penetration D in a time t for a pulse of heat applied to the surface of a medium:

$$D = (4kt)^{\frac{1}{2}} \qquad (4)$$

D = depth of penetration (cm)

$$\therefore \quad k = \frac{D^2}{4t} \qquad (5)$$

k = thermal diffusivity (cm^2/sec)

t = time for penetration (sec)

Using values of D = 90 cm and time = 2.75 days from the least squares line, k is calculated to be 8.5×10^{-3} cm^2/sec. Figure 7 from Ono (1975) gives theoretical thermal diffusivity values for sea ice as a function of salinity and temperature. The C2 site had a salinity range of $6°/_{oo}$ near the surface to $2.3°/_{oo}$ near -0.9 m and a corresponding temperature range of -17.3° C to -6.6° C. A value $k = 8.3 \times 10^{-3}$ cm^2/s is obtained from Ono's graph using $S = 2.3°/_{oo}$ and T = -6.6° C. The asymptotic nature of k with increasing temperature and the increasing salinity closer to the surface at C2 make it plausible that the thermal diffusivity remained fairly constant through the ice sheet. Assuming a

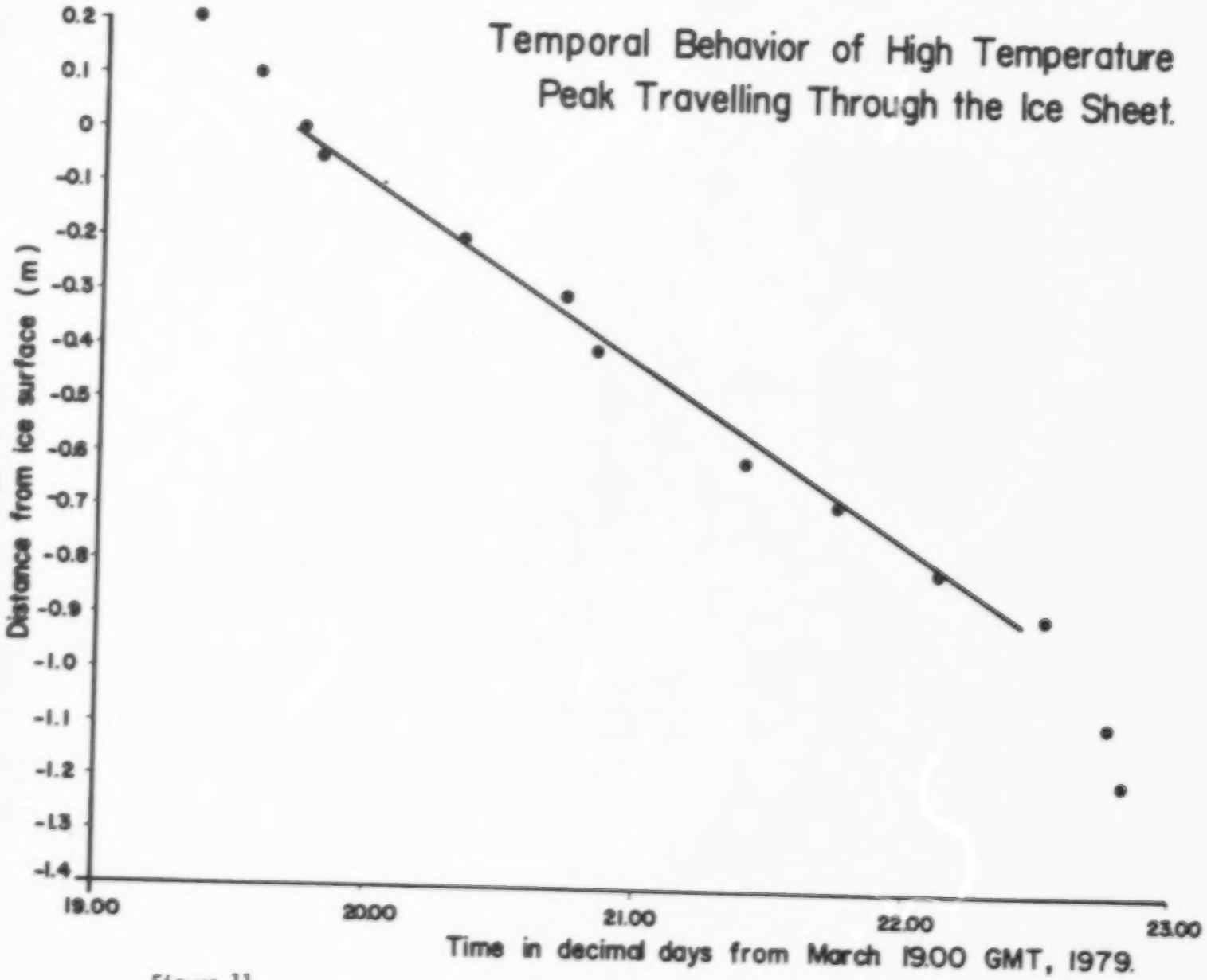

Temporal Behavior of High Temperature
Peak Travelling Through the Ice Sheet.
Distance from ice surface (m)
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
-1.1
-1.2
-1.3
-1.4
19.00
20.00
21.00
22.00
23.00
Time in decimal days from March 19.00 GMT, 1979.

Figure 11

constant thermal diffusivity, an expected range for the thermal conductivity K can be calculated from:

$$K = k\rho c \text{ (cal/cm s °C)} \quad (6)$$

where k is the thermal diffusivity (cm^2/s)

ρ is the density (g/cm^3)

c is the specific heat (cal/g-°C)

The applicable range of specific heat calculated using equation 34 from Ono is c = 0.55 cal/g-°C near the ice surface and c = 0.72 cal/g-°C about -0.9 m from the ice surface. Using a measured density ρ = 0.88 g/cm^3 (from cores C2-1 and C2-4) and the experimental thermal diffusivity k = 8.5 x 10^{-3} cm^2/s, the range of K is calculated to be from 4.1 x 10^{-3} cal/cm-s- °C near the surface to 5.4 x 10^{-3} cal/cm-s-°C about -0.9 m beneath the surface. The corresponding theoretical values for thermal conductivity K from Figure 3 of Ono are 4.9 x 10^{-3} and 5.5 x 10^{-3} respectively based on an estimated volume of air bubbles v_a = 0.05 (see Ono, 1975, Figure 2)

Ice Regrowth in the Auger Hole

To study the ice growth process in the auger hole, the time of intersection of the temperature graphs with a line through -1.5° C was recorded for each thermistor (Table 12). The value of -1.5 °C was chosen to estimate onset of the solid phase. The water temperature under C2 varied from -0.7 to -1.0° C. Figure 12 shows the very rapid growth during the first three days, levelling off to an almost constant growth rate near -1.2 m. The data from the upper probe (broken line) and the lower probe (solid line) are plotted on separate curves, because the initial rapid growth of ice on the sides of the auger hole affects the upper and lower probes differently and causes the different growth rates observed. The total time required to reach the -1.29 m ice thickness measured when the thermistor probe was installed was approximately eight days, because the diameter of the auger hole was large (15 cm) compared to the diameter of the probe (two 5 cm tubes). Due to the refreezing process described above, the growth of the ice sheet could not be measured accurately, but is estimated to be 0.6 cm/day.

Table 12
Ice Growth in Auger Hole

Distance from ice surface (m)	Temperature (°C)	Date - March 79 (decimal days)
-0.1	-1.5	12.02
-0.2	-1.5	12.10
-0.3	-1.5	12.15
-0.6	-1.5	12.37
-0.68	-1.5	12.52
-0.8	-1.5	12.75
-0.88	-1.5	12.56
-1.0	-1.5	13.54
-1.08	-1.5	13.52
-1.0	-1.5	14.98
-1.23	-1.5	16.38
-1.28	-1.5	19.90
-1.3	-1.5	20.95
-1.32	-1.5	21.89
-1.34	-1.5	24.51
-1.36	-	does not cross -1.5 °C
-1.38	-	does not cross -1.5 °C
-1.4	-	does not cross -1.5 °C

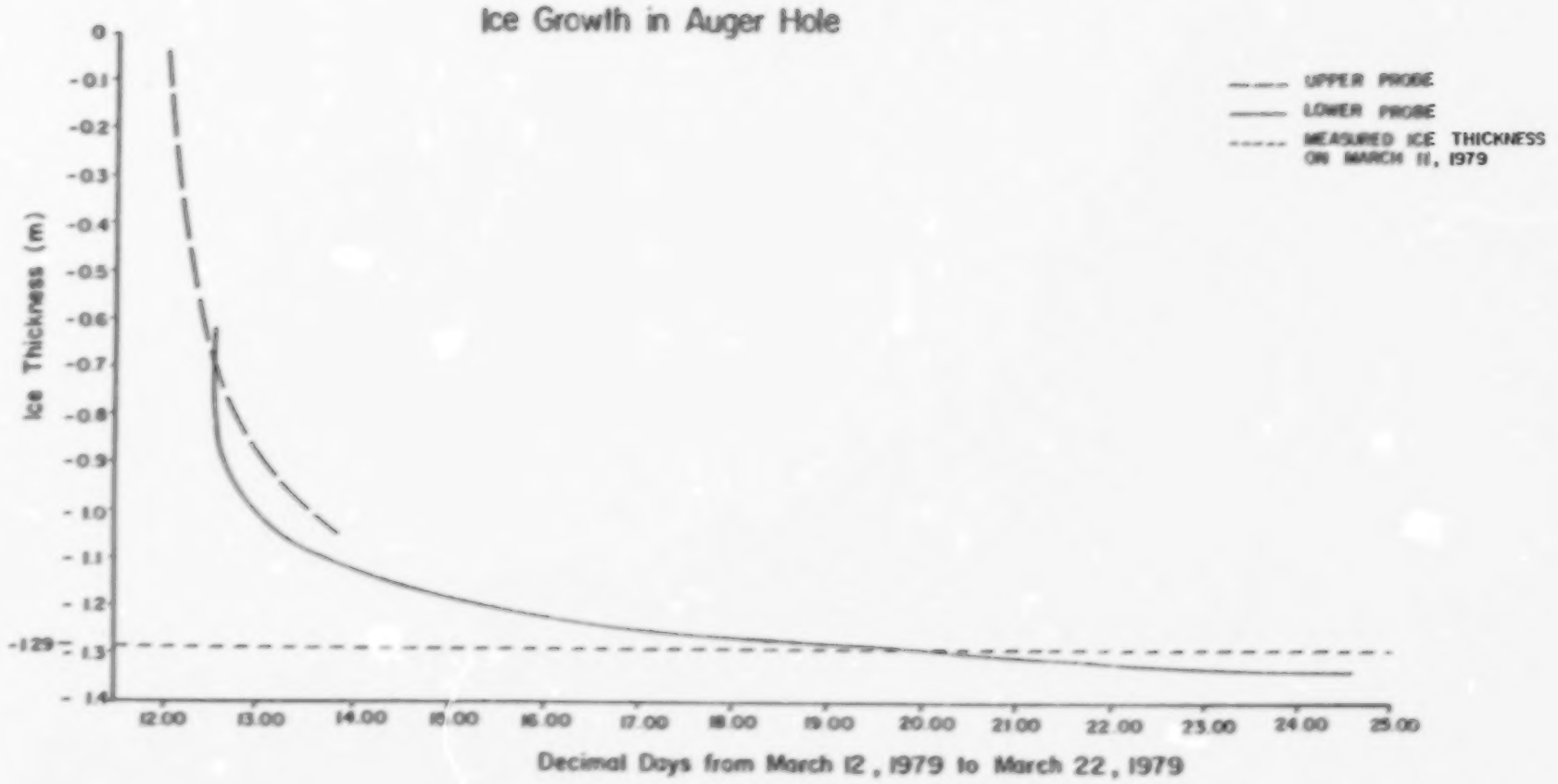


Figure 12. Ice Growth in Auger Hole

SITE C4

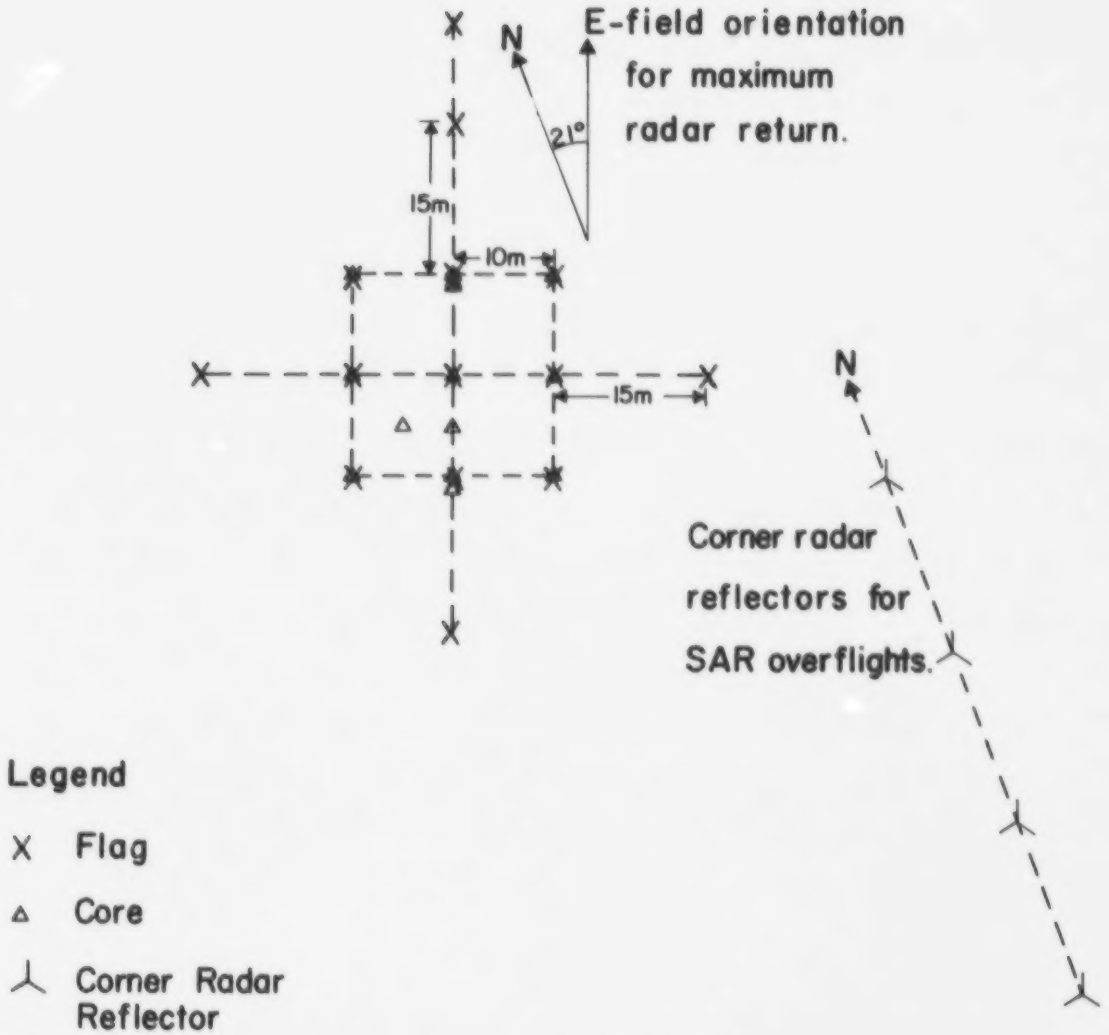
Site C4 was established as a site where the landfast first-year ice was anisotropic, as determined by the impulse radar system in an antenna rotation experiment. Site C4 corresponded to SURSAT Site A and was an important test site for researchers from N.R.C. and G.S.C. as well. The main site diagram is Figure 13.

To fully investigate the anisotropic properties, a 20 x 20 m square grid was laid out, aligned to the E-field orientation for maximum impulse radar return. See Figure 14. Cores were taken at the nine grid intersection points. Analysis of these cores for anisotropy in the crystallographic stucture is presented in a paper by Langhorne (1980). The information from the cores at Site 4 is in Core Tables 13 to 24 and Table 25 contains a summary of these core tables.

A non-recording thermistor probe was installed at Site C4, consisting of a single 5 cm diameter urethane-filled tube with thermistors installed in holes in the tube every 10 cm along the 2.5 m length. The temperature profiles obtained are shown in Figure 15 along with profiles obtained from the C2 recording thermistor probe for the same times. The raw data for the C4 temperature profiles are contained in Table 26.

Using the salinity and temperature profiles, brine volume profiles were calculated for the cores. Averaged brine volumes for the ten cores on the grid are shown in Figure 16 . Each data point represents an average brine volume for that depth, and bars represent the range from minimum to maximum brine volume at that depth over all ten cores. The brine volumes from calculated salinities are considerably larger and also have shorter min-max ranges in most cases. The high brine volumes shown near 1 m on the first two plots possibly results from using 'unsettled' temperature profiles, since

Site C4



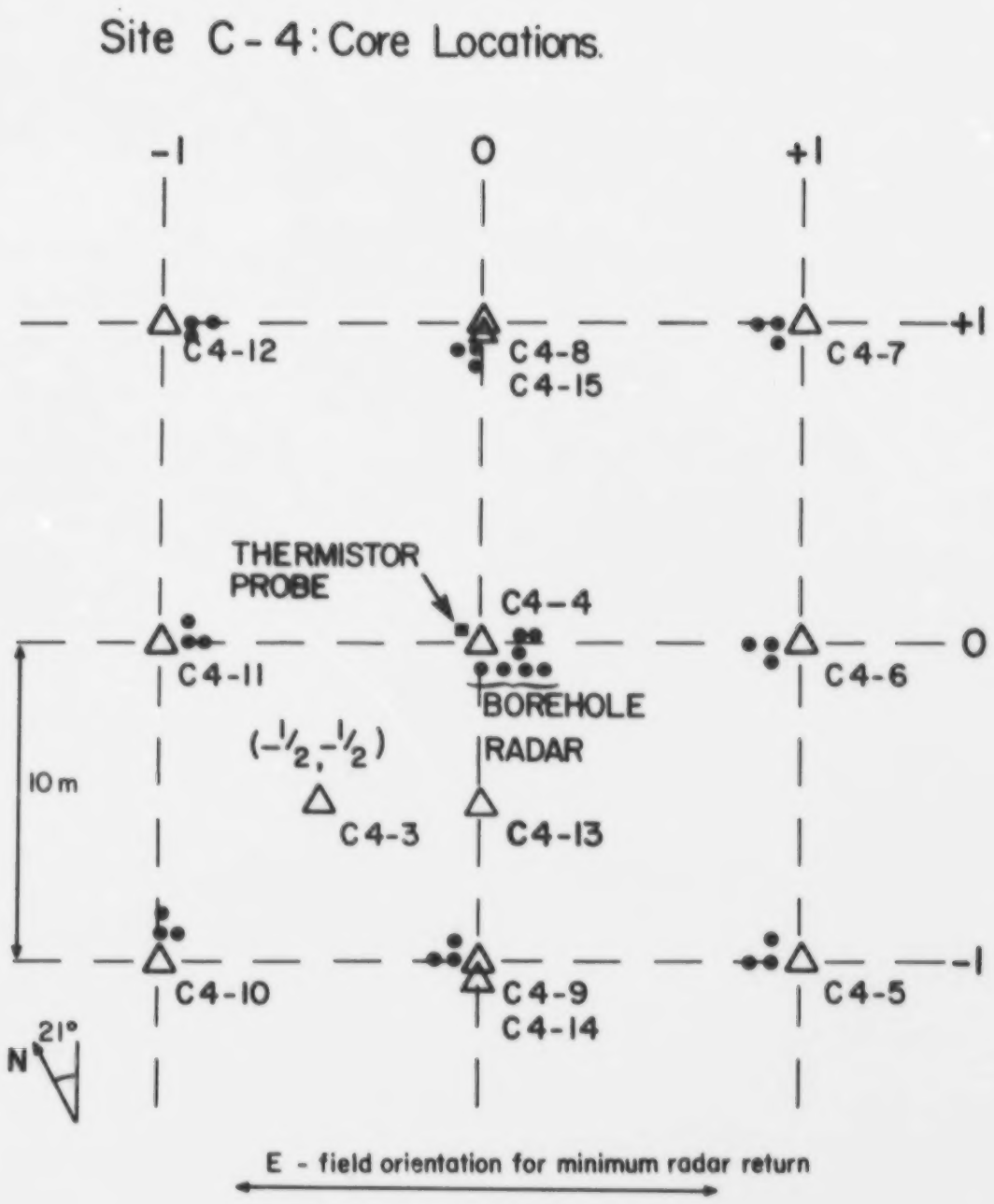
Legend

X Flag

△ Core

Corner Radar Reflector

Figure 13



Legend:

△ Core

●● TDR (9 location, 2 orientations)

Figure 14. Sketch of site C-4 showing grid and stations.

Table 13

Core C4-1

Date 12 March, 1979

Sample Code	Conductivity Micro MHOs/cm	Temp. °C	Calculated Salinity P.P.T.	Analytical Salinity P.T.T.	Ice* Temp. °C	Brine[1] Volume P.P.T.	Brine[2] Volume P.P.T.	Denisty
Site C4 Water	12200	12	9.5		-24.4+	19.3**		
C4-1 11/13	11050	11	8.8		-21.7	28.2		
C4-1 21/23	10100	11	8.2		-19.6	28.1		
C4-1 24/30								0.883
C4-1 31/33	8580	10	6.9		-17.2	25.8		
C4-1 41/43	8480	11	6.6		-14.8	27.4		
C4-1 51/53	7190	12	5.4		-12.5	25.3		
C4-1 61/63	6800	12	5.1		-10.5	27.3		
C4-1 71/73	7000	13	5.1		- 8.6	32.0		
C4-1 81/83	5630	14	4.0		- 6.3+	32.9**		
C4-1 91/93	7120	14	5.1		- 4.0	63.3		

* Ice Temperature profile from March 20, 1979

\+ Interpolated Ice Temperature

** Calculated for Interpolated Temperature

1 Brine Volume determined from calculated salinity

Text Resumes On Pg. 96

Table 14

CORE C4-2 DATE 14 March 1979

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity P.P.T.	Ice* Temp. °C	Brine[1] Volume P.P.T.	Brine[2] Volume P.P.T.	Density g/cm^3
C4-2 0/2	13900	11	11.3		-25.5	17.9		
C4-2 10/12	10280	11	8.1		-21.7	26.0		
C4-2 20/22	11680	11	9.3		-19.6	31.8		
C4-2 23/30								0.869
C4-2 30/32	10230	11	8.1		-17.2	30.3		
C4-2 40/42	9450	11	7.4		-14.8	30.7		
C4-2 50/52	9150	12	7.0		-12.5	32.9		
C4-2 60/62	6970	11	5.4		-10.5	28.9		
C4-2 70/72	7320	11	5.7		- 8.6	35.8		
C4-2 80/82	6170	11	4.7		- 6.3+	38.6**		
C4-2 90/92	4990	11	3.8		- 4.0	47.2		
C4-2 101/103	6550	13	4.8		- 2.3	100.3		

* Ice Temperature Profile from March 20, 1979
\+ Interpolated Ice Temperature
] Brine Volume Determined from Calculated Salinity
** Calculated using Interpolated Temperature

Table 15

CORE C4-3 DATE 19 March 1979 Grid Position - (-1/2, -1/2)

Sample Code	Conductivity micro MHOs/cm	Temp. ¼C	Calculated Salinity	Analytical Salinity PPT	Ice* Temp. ¼C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
C4-3 0/2	12870	13	9.8	8.3	-25.5	13.1	15.5	
C4-3 10/12	11500	13	8.7	6.3	-21.7	20.2	27.9	
C4-3 20/22	12630	13	9.6	8.2	-19.6	28.1	32.9	
C4-3 23/30								0.869
C4-6 30/32	10300	13	7.7	4.6	-17.2	17.2	28.8	
C4-3 40/42	9210	13	6.9	5.1	-14.8	21.2	28.6	
C4-3 50/52	8790	13	6.5	4.7	-12.5	22.1	30.5	
C4-3 60/62	8170	13	6.0	3.2	-10.5	17.2	32.2	
C4-3 70/72	5540	13	4.0	3.4	- 8.6	21.4	25.1	
C4-3 80/82	5840	13	4.2	2.2	-6.3+	18.1**	19.4**	
C4-3 90/92	5590	13	4.0	3.8	-4.0	47.2	49.6	
C4-3 100/102	3930	13.5	2.7	1.2	-2.3	25.1	56.4	

COMMENTS:

* Ice Temperature Profile from 20 March 1979

\+ Interpolated Ice Temperature

1 Brine Volumes calculated using Analytical Salinity

2 Brine Volumes calculated using Calculated Salinity

** Calculated using interpolated temperature

Table 16

CORE	DATE	Grid Position
C4-4	19 March, 1979	(0,0)

Sample Code	Conductivity micro MHOs/cm	Temp. ¼C	Calculated Salinity	Analytical Salinity PPT	Ice* Temp. ¼C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
C4-4 0/2	15140	13.5	11.6	9.6	-25.5	15.2	18.3	
C4-4 10/12	9450	13	7.9	5.5	-21.7	17.6	22.5	
C4-4 20/22	N.S.	N.S.	N.S.	N.S.	-19.6			
C4-4 23/30								
C4-4 30/32	9380	13	7.0	5.0	-17.2	17.8	26.2	
C4-4 40/42	8250	13	6.3	4.8	-14.8	19.9	26.1	
C4-4 50/52	6970	13	5.1	2.9	-12.5	13.6	23.9	
C4-4 60/62	6850	13.5	4.9	2.7	-10.5	14.5	26.3	
C4-4 70/72	4890	13.5	3.4	1.6	- 8.6	10.1	21.4	
C4-4 80/82	5680	13	4.1	2.4	- 6.3+	19.7**	33.7**	
C4-4 90/92	4840	13.5	3.4	3.2	-4.0	39.7	42.2	
C4-4 100/102	4130	13.5	2.9	2.8	- 2.3	58.5	60.6	

COMMENTS:

* Ice temperature profile from 20 March 1979

\+ Interpolated Ice Temperature

1 Brine Volumes calculated using Analytical Salinity

2 Brine Volumes calculated using Calculated Salinity

** Calculated using interpolated temperature

Table 17

CORE	DATE	Grid Position
C4-5	19 March 1979	(1,-1)

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity PPT	Ice* Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
C4-5 0/2	14800	13.5	11.3	7.6	-25.5	12.0	17.9	
C4-5 10/12	9670	13	7.2	5.3	-21.7	17.0	23.1	
C4-5 20/22	11280	13	8.5	6.6	-19.6	22.6	29.1	
C4-5 23/30								0.886
C4-5 30/32	9190	13.5	6.8	3.7	-17.2	13.8	25.4	
C4-5 40/42	9520	13	7.1	5.1	-14.8	21.2	29.5	
C4-5 50/52	7680	13.5	5.6	3.5	-12.5	16.4	26.3	
C4-5 60/62	6720	13	4.9	4.3	-10.5	23.1	26.3	
C4-5 70/72	5530	13	4.0	1.9	- 8.6	11.9	25.1	
C4-5 80/82	6250	13	4.5	3.5	- 6.3+	28.8**	37.0**	
C4-5 90/92	5330	12.5	3.9	2.8	- 4.0	34.7	48.4	
C4-5 100/102	4580	13.5	3.2	2.2	- 2.3	46.0	66.9	

COMMENTS:

* Ice Temperature Profile from 20 March 1979

\+ Interpolated Ice Temperature

1 Brine Volumes calculated using Analytical Salinity

2 Brine Volumes calculated using Calculated Salinity

** Calculated using interpolated temperature

Table 18

CORE	DATE	Grid Position
C4-6	20 March 1979	(1,0)

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity PPT	Ice* Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
C4-6 0/2	15580	14.5	11.6	10.1	-25.5	16.0	18.3	
C4-6 10/12	10450	14.5	76	6.0	-21.7	19.2	24.4	
C4-6 20/22	11050	14	8.1	7.2	-19.6	24.7	27.7	
C4-6 23/30								0.874
C4-6 30/32	9200	14	6.7	6.1	-17.2	22.8	25.0	
C4-6 40/42	8940	14	6.5	5.2	-14.8	21.6	27.0	
C4-6 50/52	8070	14	5.8	5.4	-12.5	25.3	27.2	
C4-6 60/62	6230	14	4.4	4.1	-10.5	22.0	23.6	
C4-6 70/72	5190	14	3.6	2.5	- 8.6	15.7	22.6	
C4-6 80/82	4780	14	3.3	1.1	- 6.3+	9.0**	27.1**	
C4-6 90/92	N.S.	N.S.	N.S.	N.S.	- 4.0	N.S.		
C4-6 100/102	4730	15	2.9	1.8	- 2.3	37.6	60.6	

COMMENTS:

* Ice Temperature Profile from 20 March 1979

\+ Interpolated Ice Temperature

1 Brine Volumes calculated using Analytical Salinity

2 Brine Volumes calculated using Calculated Salinity

** Calculated using interpolated temperature

Table 19

CORE	DATE	Grid Position
C4-7	20 March 1979	(1,1)

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity PPT	Ice* Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
C4-7 0/2	20860	16	15.4	13.1	-25.5	20.7	24.2	
C4-7 10/12	9530	15.5	6.7	6.6	-21.7	21.2	21.5	
C4-7 20/22	10580	15	7.6	6.3	-19.6	21.6	26.0	
C4-7 23/30								-.874
C4-7 30/32	8690	15	6.1	6.1	-17.2	22.8	22.8	
C4-7 40/42	8560	15	6.0	3.5	-14.8	14.5	24.9	
C4-7 50/52	8180	15	5.7	4.3	-12.5	20.2	26.8	
C4-7 60/62	5640	15	3.9	2.2	-10.5	11.8	20.9	
C4-7 70/72	6980	15.5	4.8	3.2	- 8.6	20.1	30.2	
C4-7 80/82	5150	15.5	3.5	2.7	- 6.3+	22.2**	28.8**	
C4-7 90/92	4920	15.5	3.3	N.S.	- 4.0		41.0	
C4-7 100/102	N.S	N.S.	N.S.	2.7	- 2.3	56.4		

COMMENTS:

* Ice Temperature Profile from 20 March 1979

\+ Interpolated Ice Temperature

1 Brine Volumes calculated using Analytical Salinity

2 Brine Volumes calculated using Calculated Salinity

** Calculated using interpolated temperature

Table 20

CORE	DATE	Grid Position
C4-8	20 March 1979	(0,1)

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity PPT	Ice* Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
C4-8 0/2	14650	11	11.9	7.4	-25.5	11.7	18.8	
C4-8 10/12	10650	11.5	8.3	3.3	-21.7	10.6	26.6	
C4-8 20/22	10380	11	8.2	5.7	-19.6	19.5	28.1	
C4-8 23/30								
C4-8 30/32	9450	11	7.4	5.4	-17.2	20.2	27.6	
C4-8 40/42	8870	11	6.9	6.0	-14.8	24.9	28.6	
C4-8 50/52	8550	11	6.7	4.3	-12.5	20.2	31.4	
C4-8 60/62	7350	11	5.7	3.1	-10.5	16.6	30.6	
C4-8 70/72	5370	11	4.1	2.3	- 8.6	14.4	25.8	
C4-8 80/82	5420	11.5	4.0	1.4	- 6.3+	11.5**	32.9**	
C4-8 90/92	6220	12	4.6	2.0	- 4.0	24.8	57.1	
C4-8 100/102	4390	12	3.2	1.6	- 2.3	33.4	66.9	

COMMENTS:

* Ice Temperature Profile from 20 March 1979

\+ Interpolated Ice Temperature

1 Brine Volumes calculated using Calculated Salinity

2 Brine Volumes calculated using Analytical Salinity

** Calculated using interpolated temperature

Table 21

CORE	DATE	Grid Position
C4-9	21 March 1979	(0,-1)

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity PPT	Ice* Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
C4-9 0/2	17200	17	12.2	10.2	-26.9	12.5	15.0	
C4-9 10/12	11650	17	8.0	7.3	-24.5	14.5	15.8	
C4-9 20/22	12350	17	8.5	8.3	-22.0	26.4	27.0	
C4-9 23/30								0.874
C4-9 30/32	11580	17	7.9	7.9	-19.1	27.5	27.5	
C4-9 40/42	11380	17	7.8	6.0	-16.6	23.0	29.9	
C4-9 50/52	11650	17	8.0	5.9	-14.0	25.5	34.5	
C4-9 60/62	8740	17	5.9	5.6	-12.0	27.1	28.6	
C4-9 70/72	7090	17	4.7	3.6	- 8.8	22.2	29.0	
C4-9 80/82	5370	17	3.7	3.6	- 6.3+	29.6	30.4**	
C4-9 90/92	6170	17	4.0	3.9	- 4.6	42.6	43.7	
C4-9 100/102	4460	17	2.9	2.2	- 3.6	30.1	39.7	

COMMENTS:

* Ice Temperature Profile from 21 March 1979

\+ Interpolated Ice Temperature

1 Brine Volumes calculated using Analytical Salinity

2 Brine Volumes calculated using Calculated Salinity

** Calculated using interpolated temperature

Table 22

CORE	DATE	Grid Position
C4-10	21 March 1979	(-1,-1)

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity PPT	Ice Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
C4-10 0/2	16400	16	11.9	9.5	-26.9	11.7	14.6	
C4-10 10/12	N.S.	N.S.	N.S.	N.S.	-24.5			
C4-10 20/22	11880	16	8.4	8.2	-22.0	26.1	26.7	
C4-10 23/30								0.882
C4-10 30/32	9850	16	6.8	6.8	-19.1	23.7	23.7	
C4-10 40/42	9670	16	6.7	6.8	-16.6	26.0	25.6	
C4-10 50/52	8740	16	6.0	6.2	-14.0	26.8	25.9	
C4-10 60/62	7180	16	4.9	4.6	-12.0	22.3	23.7	
C4-10 70/72	6550	16	4.4	3.2	- 8.8	19.7	27.1	
C4-10 80/82	5980	16	4.0	3.1	- 6.3+	25.5**	32.9**	
C4-10 90/92	N.S.	N.S.	N.S.	N.S.	- 4.6			
C4-10 100/102	N.S.	N.S.	N.S.	N.S.	- 3.6			

COMMENTS:

* Ice Temperature Profile from 21 March 1979

\+ Interpolated Ice Temperature

1 Brine Volumes calculated using Analytical Salinity

2 Brine Volumes calculated using Calculated Salinity

** Calculated using interpolated temperature

Table 23

CORE	DATE	GRID POSITION
C4-11	21 March, 1979	(-1,0)

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity P.P.T.	Ice Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
C4-11	15800	16.5	11.2	8.8	-26.9	10.8	13.8	
C4-11	11370	16.5	7.9	7.8	-24.5	15.4	15.6	
C4-11	11570	16.5	8.0	7.6	-22.0	24.2	25.4	
C4-11								0.882
C4-11	10380	16.5	7.1	7.3	-19.1	25.4	24.7	
C4-11	9360	16	6.5	6.2	-16.6	23.7	24.9	
C4-11	8050	16	5.5	4.4	-14.0	19.0	23.7	
C4-11	6280	16	4.2	2.7	-12.0	13.1	20.3	
C4-11	7220	16	4.9	4.8	- 8.8	29.6	30.2	
C4-11	5540	16	3.7	2.0	- 6.3+	16.4**	30.4**	
C4-11	5150	16	3.4	2.9	- 4.6	31.6	37.1	
C4-11	3660	16	2.4	N.S.	- 3.6		32.8	

COMMENTS:

* Ice Temperature Profile from 21 March 1979
\+ Interpolated Ice Temperature
1 Brine Volumes calculated using Analytical Salinity
2 Brine Volumes calculated using Calculatec Salinity
** Calculated using interpolated temperature

Table 24

CORE	DATE	Grid Position
C4-12	21 March 1979	(-1,1)

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity PPT	Ice* Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
C4-12 0/2	18600	16	13.6	N.S.	-26.9		16.7	
C4-12 10/12	11480	16	8.1	7.1	-24.5	14.1	16.0	
C4-12 20/22	12300	16.5	8.6	7.2	-22.0	22.9	27.4	
C4-12 23/30								0.880
C4-12 30/32	11180	16.5	7.7	5.9	-19.1	20.5	26.8	
C4-12 40/42	10620	16.5	7.3	6.7	-16.6	25.6	27.9	
C4-12 50/52	9980	16	6.9	5.5	-14.0	23.7	29.8	
C4-12 60/62	6890	16.5	4.6	2.8	-12.0	13.5	22.3	
C4-12 70/72	5290	16	3.5	3.3	- 8.8	20.3	21.6	
C4-12 80/82	5640	15.5	3.8	2.6	- 6.3+	21.4**	31.2**	
C4-12 90/92	4920	16	3.3	3.2	- 4.6	34.9	36.0	
C4-12 100/102	4070	16	2.7	1.6	- 3.6	21.9	37.0	

COMMENTS:

* Ice Temperature Profile from 21 March 1979

\+ Interpolated Ice Temperature

1 Brine Volumes calculated using Analytical Salinity

2 Brine Volumes calculated using Calculated Salinity

** Calculated using interpolated temperature

TABLE 25. Summary of Cores Taken at Site C-4

CORE NUMBER	DATE TAKEN	SALINITY PROFILE	DENSITY	CORE LENGTH (CM)	MEASURED ICE THICKNESS (CM)	LOCATION	FREE BOARD	FIELD PHOTOGRAPHY	COMMENTS
C4-3	3/19	from 0/2 level in 10 cm intervals to bottom of core	level 23/30	112	115	(-½,-½)	N.A.	yes	Location of threshold spot current measurements
C4-4	3/19	"	"	112	112	(0,0)	N.A.	yes	Location of non-recording thermistor probe
C4-5	3/19	"	"	111	113	(1,-1)	N.A.	yes	-
C4-6	3/20	"	"	112	115	(1,0)	N.A.	yes?	Core temperatures taken from 5 to 50 cm from top
C4-7	3/20	"	"	98	115	(1,1)	9 cm (after refrozen)	no	Bottom of core lost when taken
C4-8	3/20	"	"	112½	115	(0,1)	7 cm (after refrozen)	yes	-
C4-9	3/21	"	"	114	117	(0,-1)	13 cm	yes	Core temperatures taken from 30 to 110 cm from top
C4-10	3/21	"	level 24/30	114	117	(-1,-1)	13 cm	no	-
C4-11	3/21	"	level 23/30	113	115	(-1,0)	12½ cm	no	-
C4-12	3/21	"	"	113½	116	(-1,1)	11 cm	yes	-
C4-13	3/21	none	none	114	N.A.	(0,-½)	N.A.	no	Sectioned vertically
C4-14	3/25	none	none	118	120	(0,-1)	N.A.	no	Most carefully oriented
C4-15	3/25	none	level 23/30	N.A.	120	(0,1)	N.A.	no	Most carefully oriented

N.A. = not available

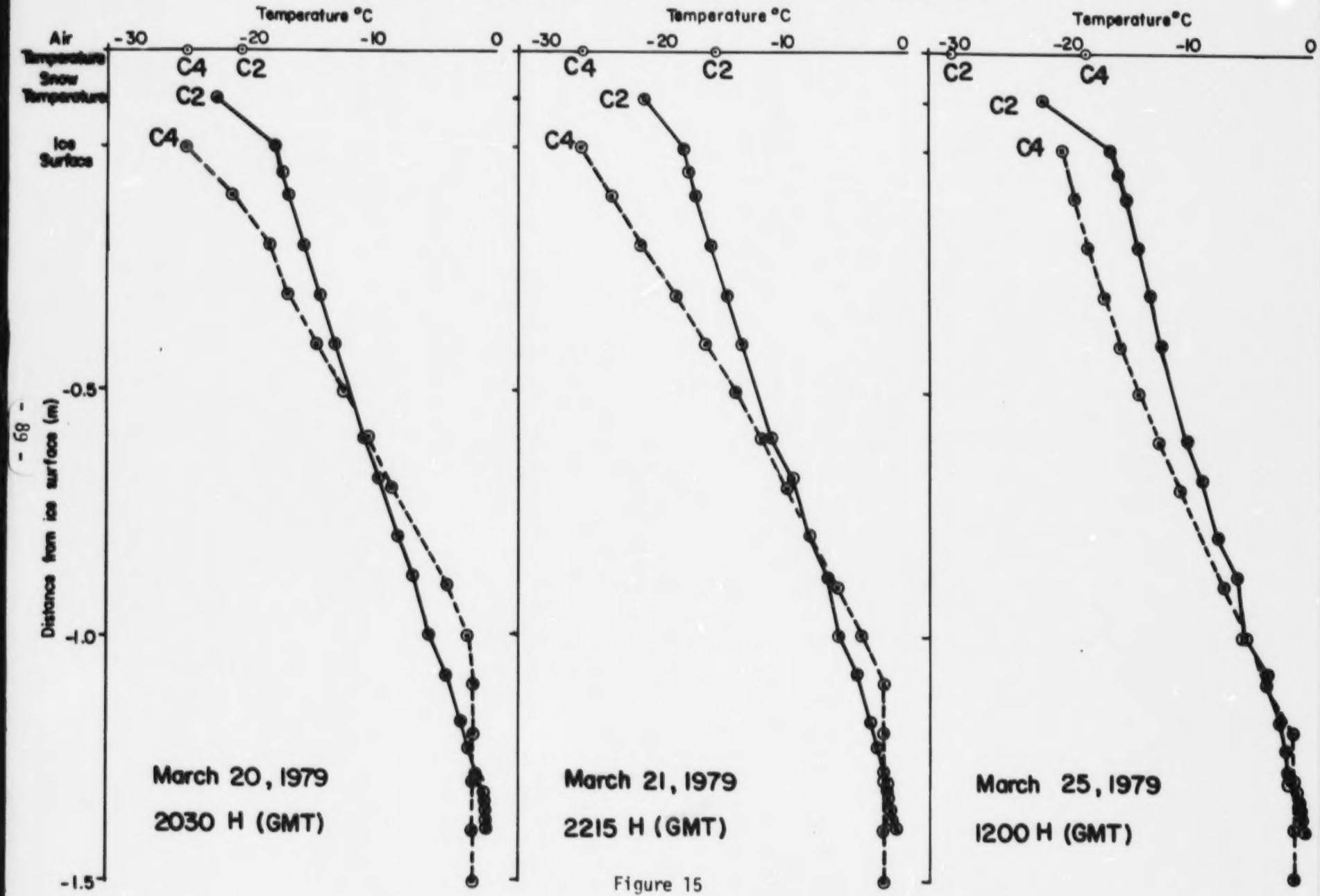

Ice Temperature Profiles Sites: C2 and C4
Temperature °C
-30
-20
-10
0
Air Temperature
Snow Temperature
Ice Surface
C4
C2
Distance from ice surface (m)
-0.5
-1.0
-1.5
March 20, 1979
2030 H (GMT)
March 21, 1979
2215 H (GMT)
March 25, 1979
1200 H (GMT)

Figure 15

Table 26 - Ice Temperature Profiles from the Non-recording Thermistor Probe
Site C4 (0,0) on the Grid

Distance from Ice Surface (m)	Thermistor #	March 20		March 21		March 25	
		Thermistor Resistance (kΩ)	Temperature (°C)	Thermistor Resistance (kΩ)	Temperature (°C)	Thermistor Resistance (kΩ)	Temperature (°C)
air	1	40.9	-25.5	44.3	-26.9	27.8	-19.1
surface	5	40.0	-25.5	41.0	-26.9	31.1	-21.1
-0.10	6	32.4	-21.7	44.3	-24.5	29.3	-20.1
-0.20	7	28.5	-19.6	38.5	-22.0	27.5	-18.9
-0.30	8	24.8	-17.2	32.8	-19.9	25.3	-17.5
-0.40	9	21.8	-14.8	27.8	-16.6	23.4	-16.2
-0.50	10	19.1	-12.5	24.0	-14.2	21.4	-14.6
-0.60	11	17.1	-10.5	20.9	-12.0	19.66	-13.0
-0.70	12	15.4	- 8.6	18.5	- 9.9	17.97	-11.3
-0.80	13	8.0?	bad thermistor	16.5	bad thermistor	13.15	bad thermistor
-0.90	14	12.1	- 4.0	5.7?	- 5.7	14.66	- 7.7
-1.00	15	11.0	- 2.3	13.2	- 3.6	13.22	- 5.7
-1.10	16	10.7	- 1.8	11.8	- 1.8	11.92	- 4.0
-1.20	17	10.8	"	10.8	"	10.75	- 1.8
-1.30	18	10.7	"	10.8	"	10.67	"

Table 26 (Con'd)

Ice Temperature Profiles from the Non-recording Thermistor Probe

Site C4 (0,0) on the Grid

Distance from Ice Surface (m)	Thermistor#	March 20		March 21		March 25	
		Thermistor Resistance (kΩ)	Temperature (°C)	Thermistor Resistance (kΩ)	Temperature (°C)	Thermistor Resistance (kΩ)	Temperature (°C)
-1.40	19	10.7	-1.8	10.7	-1.8	10.61	-1.8
-1.50	20	10.7	"	10.8	"	10.61	"
-1.60	21	10.7	"	10.7	"	10.61	"
-1.70	22	10.7	"	10.7	"	10.61	"
-1.80	23	10.7	"	10.7	"	10.61	"
-1.90	24	10.7	"	10.7	"	10.61	"

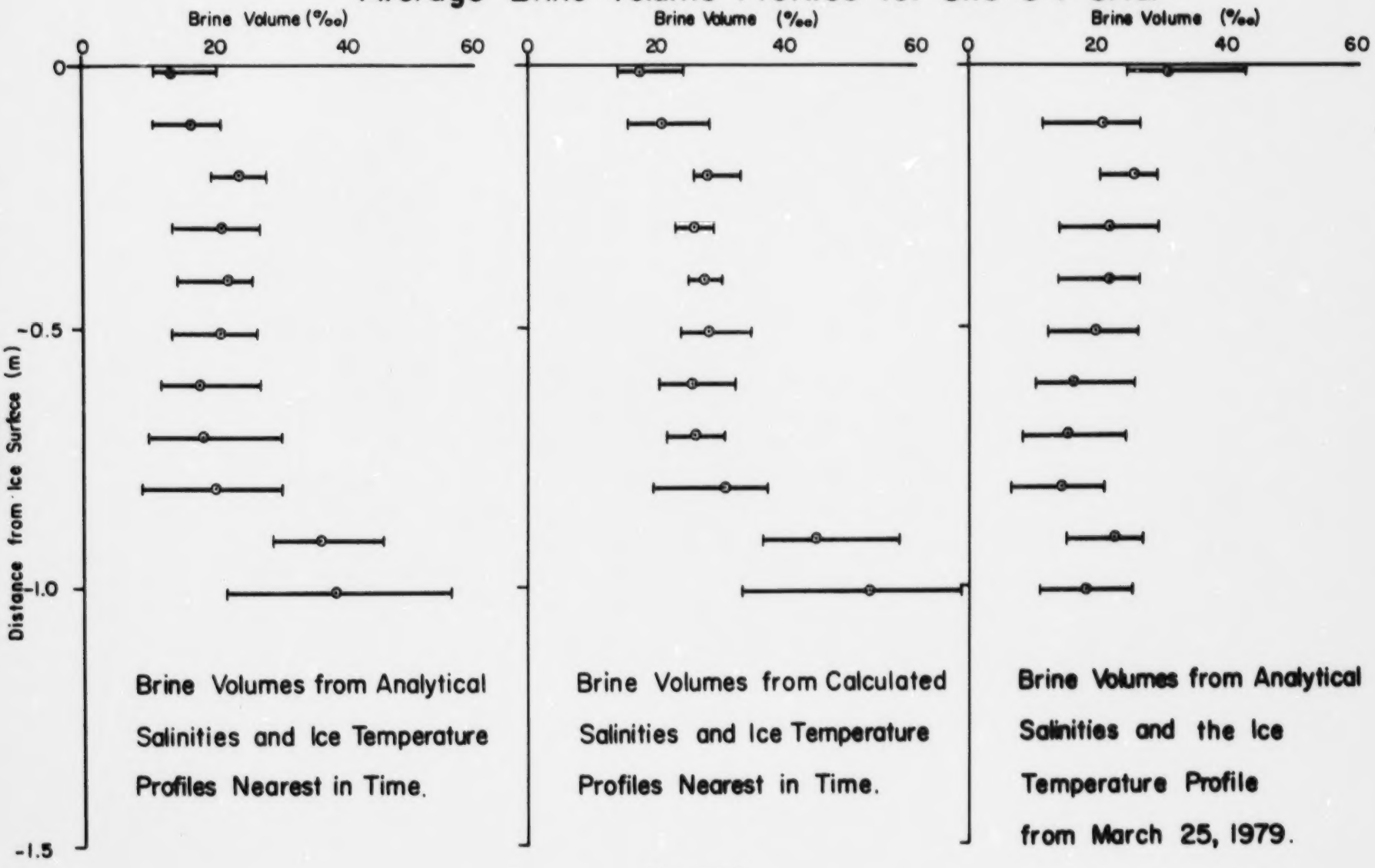

Average Brine Volume Profiles for Site C4 Grid.
Brine Volume (‰)
0
20
40
60
Distance from Ice Surface (m)
0
-0.5
-1.0
-1.5
Brine Volumes from Analytical Salinities and Ice Temperature Profiles Nearest in Time.
Brine Volumes from Calculated Salinities and Ice Temperature Profiles Nearest in Time.
Brine Volumes from Analytical Salinities and the Ice Temperature Profile from March 25, 1979.

Figure 16

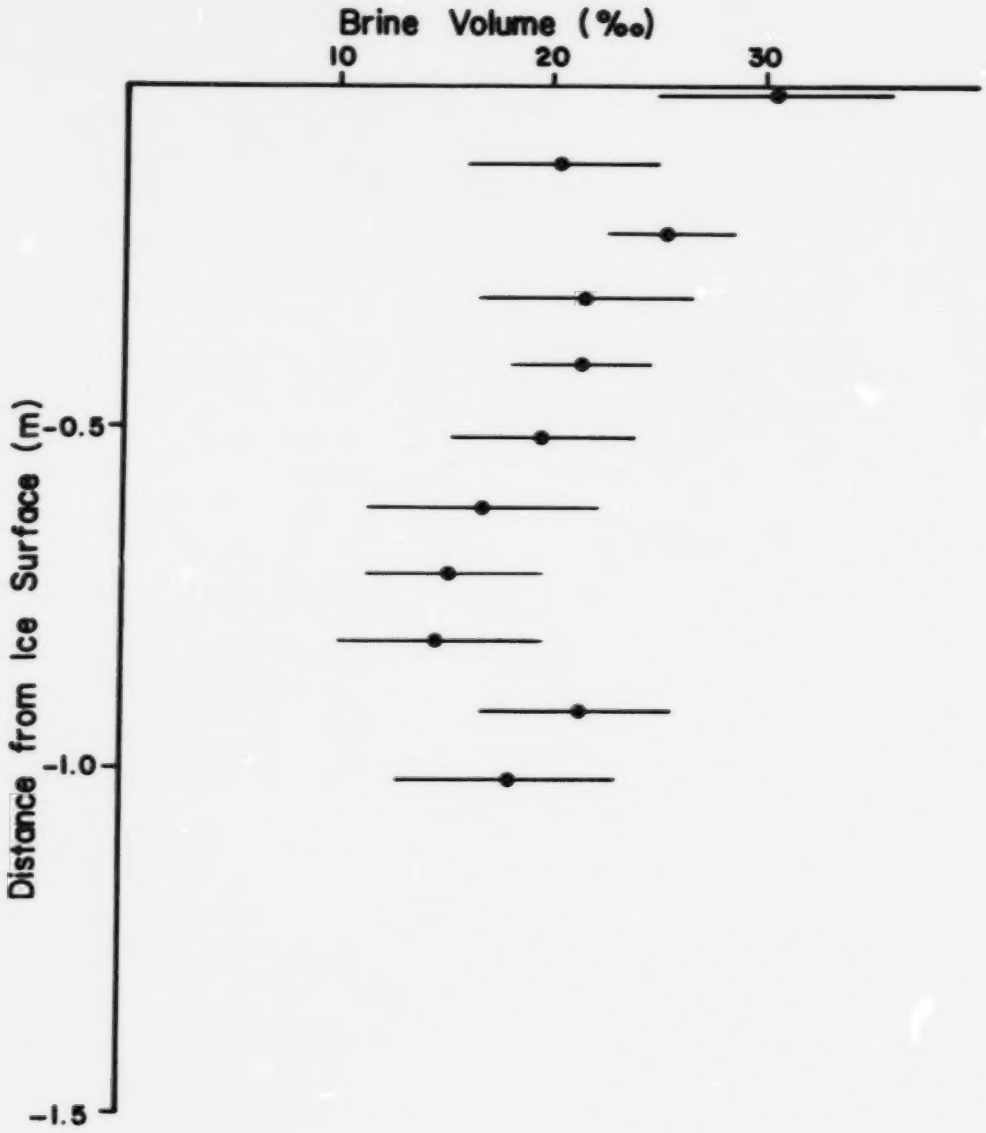


Figure 17: Calculated brine volume profile for fast ice in the Beaufort Sea, March 1979. Salinity values were averaged from measurements of ten cores taken within 10 m of thermistor chain at Site C4 (see Figure 14). Note significant variations in brine volume with depth, suggesting variations in the electrical properties of sea ice through its thickness.

Table 27

AVERAGE BRINE VOLUME PROFILE SITE C4 GRID

DEPTH (cm)	AVERAGE BRINE VOLUME (1) (ppt)	AVERAGE BRINE VOLUME (2) (ppt)	AVERAGE BRINE VOLUME (3) (ppt)
0/2	13.74	17.32	30.70
10/12	16.64	21.49	20.66
20/22	24.01	27.81	25.44
30/32	21.17	25.85	21.72
40/42	22.16	27.30	21.58
50/52	21.28	28.00	19.72
60/62	18.12	25.48	16.09
70/72	18.54	25.81	15.09
80/82	20.22	30.38	14.28
90/92	36.50	44.39	21.49
100/102	38.63	52.61	18.11

1) Brine volumes calculated using analytical salinities and the ice temperature profile nearest in time.

2) Brine volumes calculated using calculated salinities and the ice temperatures profile nearest in time.

3) Brine volumes calculated using analytical salinities and the ice temperature profile of March 25, 1979.

Table 28

AVERAGE BRINE VOLUME PROFILE SITE C4 GRID

DEPTH (cm)	AVERAGE BRINE VOLUME (ppt)	STANDARD DEVIATION (σ)
0/2	30.70	5.6
10/12	20.66	4.5
20/22	25.44	3.2
30/32	21.72	4.7
40/42	21.58	3.9
50/52	19.72	4.4
60/62	16.09	4.9
70/72	15.09	4.7
80/82	14.28	4.8
90/92	21.49	4.1
100/102	18.11	5.1

Brine volume calculated using analytical salinity and the March 25, 1979 ice temperature profile.

it does not appear so large in the third plot (calculated using the March 25 Ice Temperature C4-15). Figure 17 shows average brine volumes of the ten cores on the grid, calculated using the Ice Temperature Profile from March 25, with standard deviation of the brine volumes instead of min-max ranges (Table 28).

SITES C5 AND C6

Sites C5 and C6 were used to study the character of the edges of refrozen leads and the thicker first-year ice that separated to form the leads. Cores C5-1 and C5-2 were taken on the southern edge of a newly refrozen lead a few km north of Site C4 (Table 29).
The refrozen lead at C5 was covered with ice flowers. Core C6-1 was taken on a refrozen lead about 8 km north of Site C5, and Core C6-2 was taken on the thicker first-year ice near the edge of the lead (Table 30). The refrozen lead at C6 was covered with a slush layer.

Table 29. Core Data, Site C-5

CORES C5-1 & C5-2

DATE 12 March, 1979

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity PPT	Analytical Salinity PPT	Ice Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm[3]
C5-1 0/2	18800	12	15.2					
C5-1 11/13	14390	11	11/7					
C5-1 22/24	11900	12	9.3					0.862
C5-1 25/30								
C5-1 31/36	12200	12	9.5					
C5-2 2/4	14410	13	11.1					
C5-2 11/13	16400	14	12.5					
C5-2 21/23	14420	14	10.8					

Table 30

CORES
C6-1 and C6-2

DATE
12 March, 1979

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity PPT	Ice Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
Site 6 Water	35000	21	24.1					
C6-1 0/2	26100	12	21.8					
C6-1 10/12	14750	17	10.3					
C6-1 20/22	11370	17	7.8					
C6-2 0/2	20600	16	15.2					
C6-2 10/12	9730	17	6.6					
C6-2 20/22	10180	16	7.1					
C6-2 23/30								0.875
C6-2 30/32	N.S.	N.S.	N.S.					
C6-2 40/42	8530	16	5.8					
C6-2 50/52	11760	16	8.3					
C6-2 60/62	8550	16	5.9					
C6-2 70/72	8240	16	5.6					
C6-2 80/82	8230	16	5.6					
C6-2 90/92	9220	16	6.4					
C6-2 100/102	6770	18	4.4					
C6-2 110/112	6230	18	4.0					
C6-2 121/125	13290	18	9.0					

COMMENTS:

SITES AC 2, NORDA 2 and NORDA 5

These sites were of prime interest to other researchers, and only a limited amount of information is available. Figure 18 presents Partial Ice Temperature Profiles from the sites.

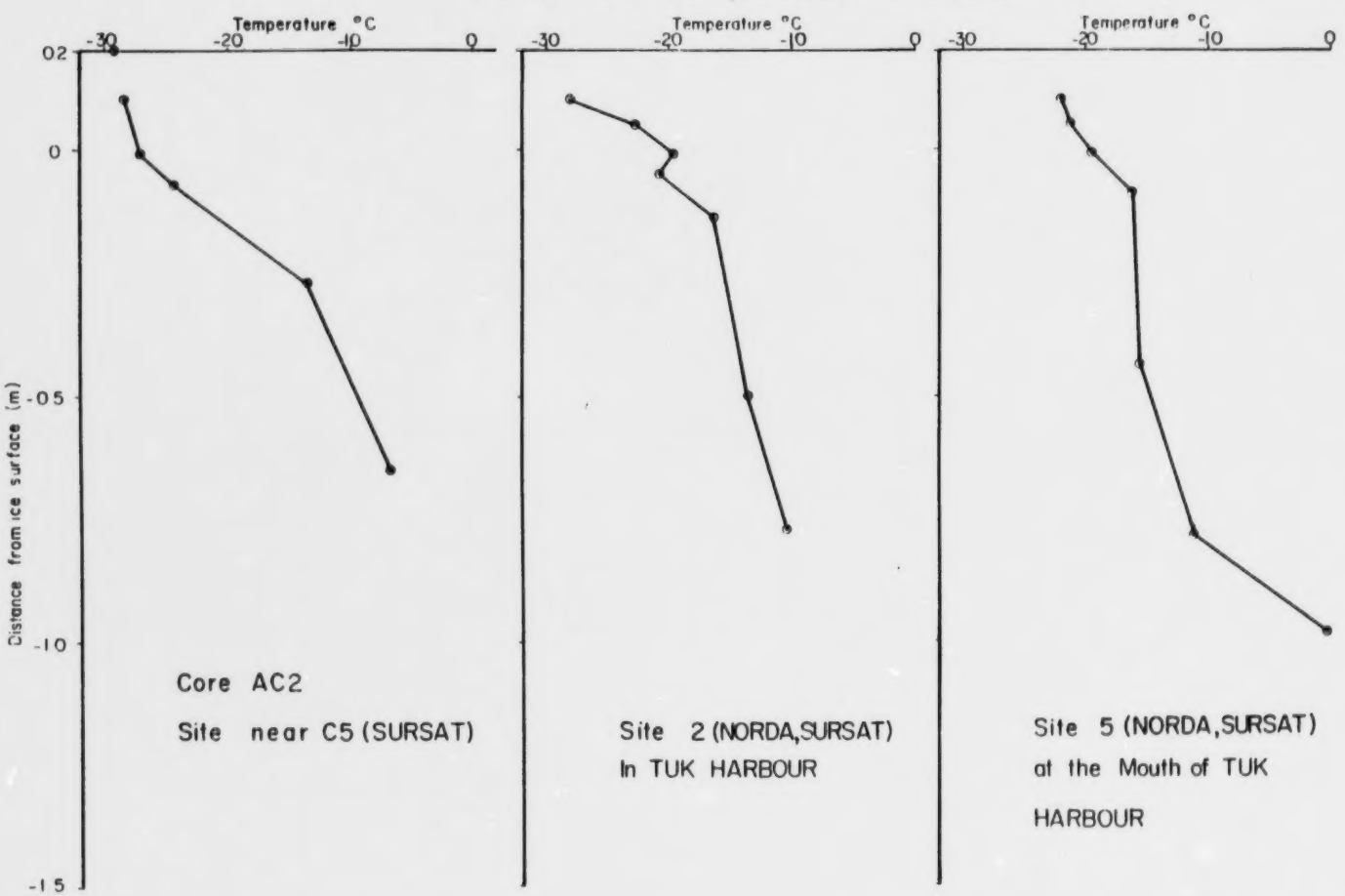

Partial Ice Temperature Profiles.
Temperature °C
-30
-20
-10
0
02
0
-05
-10
-15
Distance from ice surface (m)
Core AC2
Site near C5 (SURSAT)
Site 2 (NORDA,SURSAT)
In TUK HARBOUR
Site 5 (NORDA,SURSAT)
at the Mouth of TUK
HARBOUR

Figure 18

THE MULTI-YEAR ICE SITE

The C-CORE multi-year ice site was located in the vicinity of ice island T3, and was near the area of multi-year ice studied by SURSAT (Figure 19). The site was laid out in two lines, not at right angles to each other; the longer line referred to as Leg 1, and the shorter line, as Leg 2. The site diagram, Figure 19 , was drawn from low level photographs taken during the impulse radar runs. The ice thickness measurements made at the stations along the two legs are found in Table 31 . The information obtained from the cores at the multi-year site is in Tables 32, 33, 34 and 35 . A graph of the ice temperature profile for Core IM, obtained by inserting thermistors into the core upon removal, is shown in Figure 3 of the Surface Measurements - Ice Temperature Profiles section (p.18).

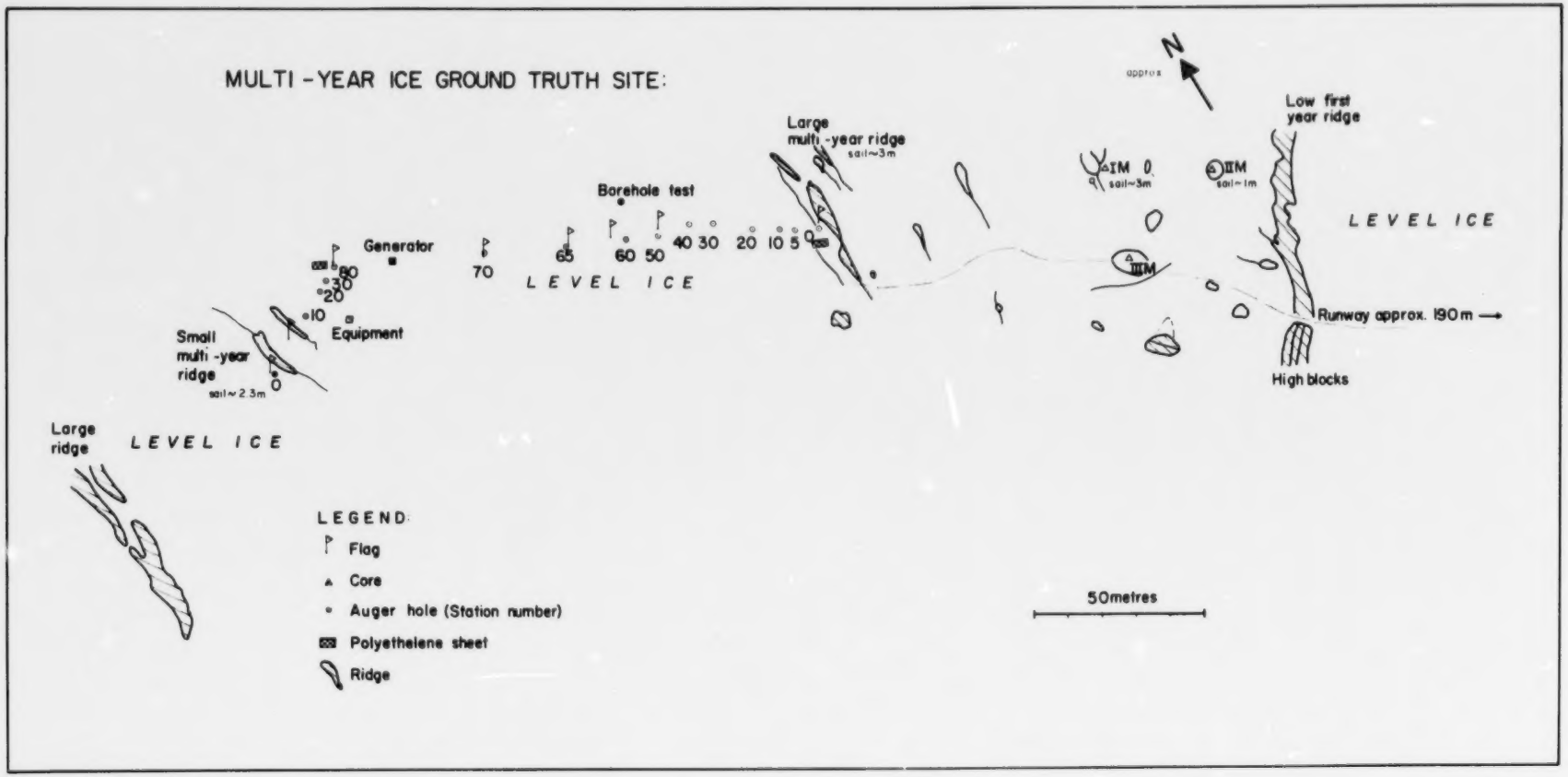

MULTI-YEAR ICE GROUND TRUTH SITE:
approx
N
Low first year ridge
Large multi-year ridge
sail~3m
Borehole test
IM
sail~3m
IIM
sail~1m
LEVEL ICE
Generator
70
65
60 50
40 30
20
10 5
0
LEVEL ICE
80
30
20
10
Equipment
IIIM
Runway approx. 190m
Small multi-year ridge
sail~2.3m
0
High blocks
Large ridge
LEVEL ICE
LEGEND
Flag
Core
Auger hole (Station number)
Polyethelene sheet
Ridge
50metres

Figure 19

Table 31

Multi-year Ice Site: Ground Truth Thickness

	STATION	DISTANCE (M) MEASURED ON ICE	THICKNESS OF ICE (M)
Line 1	0	0	-
	5	~3.7	10.3
	10	12.2	8.5
	20	22.0	8.4
	30	32.0	5.9
	40	42.4	5.7
	50	52.7	5.6
	60	67.1	5.5
	65	~71.1	5.8
	70	105.5	2.5
	80	149.4	2.2
Line 2	0	0	8.5
	5	1.8	6.8
	10	9.2	8.8
	20	18.3	5.2
	30	27.4	3.1

Table 32

CORE
IM (Large Hummock)

DATE
14 March 1979

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity PPT	Analytical Salinity PPT	Ice Temp. °C	Brine[1] Volume PPT	DENSITY g/cm^3	COMMENTS
Air					-30.0			Bottom 1.5cm of layer for 5.
Snow			0.05		-28.5			
IM	4				-28.5			
IM	23				-28.0			
IM	26		0.18		-27.9*	0.2		Thin section
IM	30				-27.8			
IM	64		0.30		-26.2*	0.4		Thin section
IM	78				-26.0			
IM	90				-14.5			
IM	111		0.60		-24.1*	1.3		Thin section
IM	118				-24.2			
IM	145				-24.0			
	149		1.08		-22.4*	3.4		Thin section
IM	155				-20.5			

*Ice temperature obtained from least squares line through known ice temperatures.

Table 33

CORE
IV M Shallow Meltpond

DATE
14 March 1979

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity PPT	Ice Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
IV M 5/10			0.70					
IV M 15/20			0.70					
IV M 25/30			1.13					
IV M 35/40			0.45					
IV M 45/50			0.47					
IV M 55/60			0.35					
IV M 65/70			0.10					
IV M 75/80			0.05					
IV M 85/89			0.08					

Table 34

CORE Cm-1

DATE 15 March, 1979

Sample Code	Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity PPT	Ice Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
Cm1 0/2	252	17	0.15					
Cm1 10/12	1025	14	0.68					
Cm1 13/20								0.774
Cm1 20/22	1448	14	0.99					
Cm1 23/30								0.870
Cm1 30/32	1182	13	0.80					
Cm1 40/42	2590	14	1.8					
Cm1 50/52	3420	13	2.4					
Cm1 60/62	4380	14	3.0					
Cm1 70/72	6200	15	4.3					
Cm1 80/82	5500	16	3.7					

COMMENTS:

Table 35

CORE
Cm-2

DATE
15 March 1979

Sample Code		Conductivity micro MHOs/cm	Temp. °C	Calculated Salinity	Analytical Salinity PPT	Ice Temp. °C	Brine[1] Volume PPT	Brine[2] Volume PPT	Density g/cm^3
Cm-2	02/2	32.7	16	0.020					
Cm-2	10/12	18.6	16	0.012					
Cm-2	20/22	11.6	16	7.2×10^{-3}					
Cm-2	23/30								0.783
Cm-2	30/32	32.3	17	0.020					
Cm-2	40/42	35.3	16	0.022					
Cm-2	50/52	59	17	0.036					
Cm-2	60/62	98	18	0.058					
Cm-2	70/72	202	18	0.12					
Cm-2	80/82	327	18	0.19					

COMMENTS:

REFERENCES

Annan, A.P. and Davis, J.L., 1976, "Impulse Radar Sounding in Permafrost", Rad. Sci. Vol. 11, pp. 383-394.

Assur, A. (1958), "Composition of Sea Ice and its Tensile Strength," Arctic Sea Ice, N.A.S. Publication 598, Washington, pp. 106-138.

Bogorodsky, V.V., 1980, "Techniques for Remote Sensing of Sea Ice Thickness", Proceedings of the International Workshop on the Remote Estimation of Sea Ice Thickness, St. John's, September 25-26, 1979. pp. 361-372, C-CORE Publication 80-5.

Butt, K.A. and Gamberg, J.B., 1980, "Technology of Airborne Impulse Radar for Sounding Sea Ice", Proceedings of the International Workshop on the Remote Estimation of Sea Ice Thickness, St. John's, September 25-26, 1979. pp 385-412, C-CORE Publication 80-5.

Butt, K.A., Gamberg, J.B., and Rossiter, J.R. 1979, "Remote Estimation of the Properties of Sea Ice, Impulse Radar Study of Lake Melville, Labrador", C-CORE Data Report, 248 pp.

Campbell, W.J., Ramseier, R.O., Weeks, W.F. and Gloersen, P., 1975, "An Integrated Approach to the Remote Sensing of Floating Ice", Proceedings of the Third Canadian Symposium on Remote Sensing, Edmonton, September 22-24, 1975, pp. 39-72.

Davis, J.L., Topp, G.C. and Annan, A.D., 1977, "Measuring Soil Water Content in situ Using Time-Domain Reflectormetry Techniques", Geology Survey Canada, Paper 77-113, pp 33-36.

Frankenstein, G.E. and Gardner, R., (1967), "Equations for Determining the Brine Volume of Sea Ice from -0.5°C to -22.9°C", J. Glaciol. Vol. 6 No. 48 pp. 943-944.

Hoekstra, P., Sartorelli, A. and Shinde, S., 1980, "Electromagnetic Methods for Sea Ice Thickness Measurements", Proceedings of the International Workshop on the Remote Estimation of Sea Ice Thickness, St. John's, September 25-26, 1979. pp. 313-330, C-CORE Publication 80-5.

Hunt, F.R., 1979, "A Sea Ice Thickness Radar Operating in the High Frequency Band", Proceedings of the International Workshop on the Remote Estimation of Sea Ice Thickness, St. John's, September 25-26, 1979. pp. 373-384. C-CORE Publication 80-5.

Keelty, J.M. and Tam, S.Y.K., 1980, "Synthetic Pulse Radar Design", Proceedings of the International Workshop on the Remote Estimation of Sea Ice Thickness, St. John's, September 25-26, 1979. pp. 349-360. C-CORE Publication 80-5.

Kovacs, A. and Morey, R.M., 1980, "Anisotropic Properties of Sea Ice in the 50-150 MHz Range", Proceedings of the International Workshop on the Remote Estimation of Sea Ice Thickness, St. John's, September 25-26, 1979, pp. 155-188. C-CORE Publication 80-5.

Langhorne, P., (1980), "Crystal Anisotropy in Sea Ice", Proceedings of the International Workshop on the Remote Estimation of Sea Ice Thickness, St. John's, September 25-26, 1979. pp 189-224, C-CORE Publication 80-5.

Langhorne, P., Rossiter, J.R. and Keliher, T.E., 1980, "Remote Estimation of Sea Ice Properties, Ice Core Analysis Beaufort Sea, March 1979", C-CORE Publication 80-7.

Mercer, J.B., 1980, "Remote Sounding of Sea Ice - Past, Present, and Future Applications", Proceedings of the International Workshop on the Remote Estimation of Sea Ice Thickness, St. John's, September 25-26, 1979.

Ono, N., (1975), "Thermal Properties of Sea Ice IV. Thermal Constants of Sea Ice", CRREL Draft Translation 467, 19 pp.

Oswald, G.K.A., 1980, "Bulk Surveying of Sea Ice", Proceedings of the International Workshop on the Remote Estimation of Sea Ice Thickness, St. John's, September 25-26, 1979. pp. 413-420, C-CORE Publication 80-5.

Robertson, D.E., (1972), "Salinity Reductions Resulting from Freezing Seawater in Polyethylene Bottles", Journal of the Oceanographic Society of Japan, Vol. 28, No. 1, pp. 37-38, February 1972.

Rossiter, J.R., 1980, "Review of Impulse Radar Sounding of Sea Ice", Proceedings of the International Workshop on the Remote Estimation of Sea Ice Thickness, St. John's, September 25-26, 1979. pp. 77-108, C-CORE Publication 80-5.

Rossiter, James R. and Butt, Kenneth, A., "Remote Estimation of the Properties of Sea Ice, Beaufort Sea Field Trip Report - March 1979", C-CORE Data Report, 36 pp.

Rossiter, James R., Langhorne, P., Ridings, T. and Allan, A.J., 1977, "Study of Sea Ice Using Impulse Radar", Proceedings of the Fourth International Conference on Port and Ocean Engineering under Arctic Conditions, St. John's, September 26-30, 1977, pp. 556-567.

Tam, S.Y.K. and Keelty, J.M., 1980, "Some Tests of a VHF Synthetic Pulse Sea Ice Thickness Sensor", Proceedings of the International Workshop on the Remote Estimation of Sea Ice Thickness, St. John's, September 25-26, 1979. pp. 305-312, C-CORE Publication 80-5.